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A SERIES OF TEXTBOOKS PREPARED FOR THE STUDENTS OF THE INTERNATIONAL CORRESPONDENCE SCHOOLS AND CONTAINING IN PERMANENT FORM THE INSTRUCTION PAPERS, EXAMINATION QUESTIONS, AND KEYS USED IN THEIR VARIOUS COURSES

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INCANDESCENT AND ARC LIGHTING
ELECTRIC-RAILWAY STATION EQUIPMENT
INTERIOR WIRING
MERCURY-VAPOR CONVERTERS
VOLTAGE REGULATION
MODERN ELECTRIC-LIGHTING DEVICES
ELECTRIC SIGNS
ELECTRIC HEATING

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CONTENTS

INCANDESCENT AND ARC LIGHTING

INCANDESCENT LAMPS

1. While it is not absolutely necessary for a wireman to be thoroughly familiar with the details of all the appliances to which he makes connections, he will find it greatly to his advantage to obtain all the information he can concerning them. However, he should be so familiar with the general characteristics of such appliances as to be able to detect errors in their location or distribution, or to recommend, or even design, an advantageous layout that will produce the results desired. For example, he should know something of the construction and properties of both arc and incandescent lamps, as well as of the various devices that must accompany electric lamps in order to make them most useful. He should know where and how to place the lamps and how to select the proper shades and reflectors, so as to direct the greatest possible amount of light to the points where it is most needed.

The discovery of electric lamps has practically revolutionized the art of illumination. White light, or sunlight, is composed of the so-called *prismatic colors*, or the colors that appear in the rainbow. Hence, any artificial light containing these colors in the proper proportions furnishes illumination equal in quality to sunlight. This is now nearly accomplished by some types of modern electric lamps, especially when equipped with shades or globes that absorb any excess quantities of some of the colors.

The two types of lamps commonly used for producing electric light are *incandescent lamps* and *arc lamps*. Incandescent lamps are most largely employed for interior lighting, and arc lamps for street lighting. The former, however, are sometimes used for street lighting, while the latter are now much used for interior lighting.

LAMP CONSTRUCTION

2. Whenever a current of electricity is forced through a conductor, heat is generated in the conductor, due to its resistance to the passage of the current. The heat thus produced is proportional to the product of the square of the current and the resistance of the conductor; that is, if I is the current and R the resistance, the heat is equal to $I^2 R$. If, by increasing either the current or the resistance, or both, this quantity of heat is made great enough, the conductor will become very hot, and will glow or become incandescent with heat. If this action occurs in open air, the conductor will almost immediately burn off; but in a vacuum, or a space from which the air has been removed, the conductor will remain incandescent for a considerable time.

3. An **incandescent lamp** consists essentially of an electric conductor inside a sealed glass bulb from which the air has been exhausted. The conductor is called the **lamp filament.** In order to produce the heat required for incandescence and still keep the current down to a value that is commercially possible, the resistance of the filament must be very high. A great deal of experimental work has been done to bring lamp filaments to their present state of perfection. Most carbon filaments are now made by chemically dissolving cotton and squirting the pulpy mass through small orifices, from which the threads drop into alcohol and become hardened. They are then washed, dried, and treated with gasoline vapor, which forms a layer of graphite carbon on the outside. It is the graphite that gives the filament its steel-like appearance.

It has been found that if the filaments, after the foregoing processes, are subjected to a very intense heat at atmospheric pressure, the graphite coating undergoes a change that reduces its resistance and renders it more nearly pure carbon. This change also causes the resistance of the filament to increase as its temperature is increased by the passage of an electric current; the resistance of the ordinary carbon filament decreases with increasing temperature. Filaments so treated are said to be *metallized*, because their properties so much resemble those of metals. Filaments made of some of the rare metals, such as tantalum, osmium, and tungsten, are also coming into use.

4. The **leading-in wires** are the connections through the glass stopper or neck of the bulb. They are made of platinum, because this metal contracts and expands under changing temperatures at very nearly the same rate as glass. In Fig. 1 is shown some forms of lamp filaments and the position of the leading-in wires: (*a*) shows a plain loop filament, (*b*) the spiral, and (*c*) the oval. The filament shown in (*c*) is *anchored* at *x* by a small iron or nickel wire fused into the glass, which is done to prevent injury by vibration. Lamps with either plain loop filaments or anchored filaments should be selected for use where there is likely to be severe vibration, as, for example, on trolley cars. The leading-in wires extend from their junction with the ends of the filament at *a*, *a* through the glass to the junction with the copper leads at *c*. The ends *b*, *b* of the leads are attached to the base.

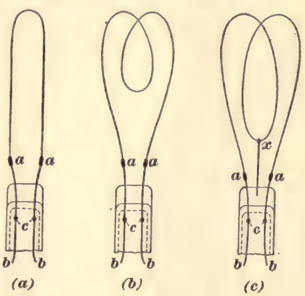


FIG. 1

5. The **glass bulb,** Fig. 2, is usually pear-shaped or very nearly so. For purely illuminating purposes, the bulb

is either plain or frosted, while for decorative or advertising purposes, it is often colored. The size of bulb for each lamp rating is that which experience has shown to be most satisfactory. If too small, the glass becomes more quickly blackened by small particles of carbon torn from the filament. This blackening occurs to some extent on the inner surface of all bulbs, but the deposit must necessarily be thicker in a small bulb than in a large one.

6. Assembling the Lamp.—In assembling the parts of the lamp, the leading-in wires are first fastened to the ends of the copper leads by melting, or fusing, the copper

FIG. 2

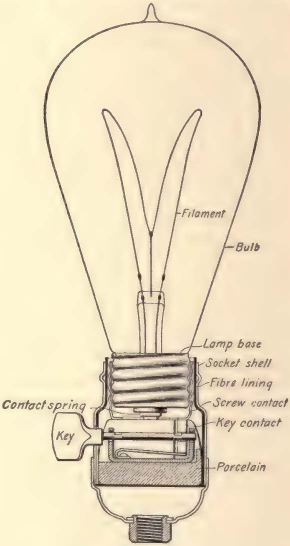


FIG. 3

about the platinum. After this operation, a portion of the platinum and its joint with the copper is sealed into the glass stem, and the filament is cemented to the projecting ends of the leading-in wires by a carbon paste. The filament

is then pushed into the bulb, to the top of which has previously been attached a small glass tube, as shown in Fig. 2, and the stopper is sealed into the neck, thus closing that end. The bulb is then exhausted through the small tube by a process that combines the use of an air pump and a chemical—the air pump to remove the larger portion of the air, and the chemical to combine with or consume the small amount of oxygen (the active element of air) that remains. As soon as this chemical combination takes place, the bulb is sealed off by heating the contraction at *a*, which is closed by the pressure of air on the outside; this leaves the tip on the lamp. The neck of the lamp is then fastened into the base by a setting of plaster of Paris or cement, the rib *b* preventing the base from pulling off the bulb.

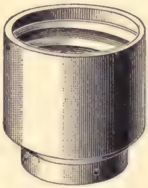


Fig. 4

Fig. 3 shows a lamp with an Edison base screwed into a key socket, and Fig. 4 shows an adapter for changing from Thomson-Houston (abbreviated T.-H.) to Edison sockets. Edison bases are superseding all other types of bases, and adapters are frequently used in making other sockets suitable to receive Edison base lamps.

LAMP PROPERTIES

7. Rating of Lamps.—In English-speaking countries, it was formerly the custom to compare all light sources with the light from spermaceti candles of standard dimensions; hence, incandescent lamps are usually rated in **candlepower** (abbreviated c. p.). In the United States, the present recognized standard is the German Hefner lamp, burning amyl acetate and having a flame of standard dimensions. The light given by such a lamp is called a **hefner.** The ratio of hefners to candlepower is 88 to 100, that is, 1 hefner is equal to .88 candlepower.

8. Light Distribution.—The light-giving power of a lamp is not definitely specified by stating its candlepower,

unless it is also stated from what portion of the lamp the light is given. For example, in Fig. 5, the amount of light given off in different horizontal directions, as at *1*, *2*, *3*, *4*, etc., is not necessarily the same. The distance in any direction from the center of the lamp to the irregular curve indicates

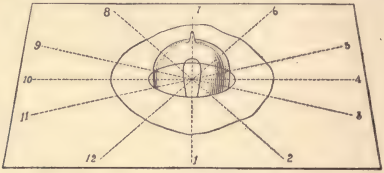


FIG. 5

the candlepower given off in that direction. The average of the candlepowers measured in each of a number of equally distributed horizontal directions is known as the **mean horizontal candlepower**; this is frequently measured as the lamp rotates rapidly about its vertical axis.

9. Fig. 6 illustrates the *vertical distribution* of light about a lamp. This distribution is least at the base, or position *1*, because this part is in the shadow; the light increases to a maximum at points *2* and *4*, and decreases again at point *3*, because from this point less of the filament can be seen, and also because the tip cuts off some of the light. Some lamps are made with the filament so coiled as to throw a large part of the light from the tip end. Some manufacturers are also offering a tipless lamp, in which the tube for exhausting the air from the bulb passes through the neck between the leading-in wires.

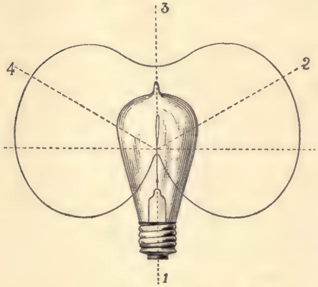


FIG. 6

10. If a lamp is so hung that its candlepower can be measured from any direction, and if readings are taken from a number of equally spaced intervals all around the lamp, the average of these readings will be the **mean spherical candlepower.** This term means the average of the candlepower given out in all directions. The mean spherical candlepower is not of great importance in incandescent lamps, as the larger portion of the light is generally wanted in a more confined space; that is, the half sphere, or hemisphere, below the lamp. The *mean hemispherical candlepower* is important when a lamp is suspended at some height to illuminate a large space underneath.

Incandescent lamps are made in a variety of sizes, the most common candlepowers being 4, 8, 10, 16, 20, 32, 50, and 100. For general purposes, 16-candlepower lamps are most common, while for decorative and advertising purposes, small lamps of $\frac{1}{2}$, 1, and 2 candlepower are used.

11. The **specific consumption**—often improperly called the **efficiency**—of incandescent lamps is expressed in watts per mean horizontal candlepower. For example, a lamp consuming 49.6 watts and giving out 16 candlepower consumes 3.1 watts per candlepower ($49.6 \div 16 = 3.1$) and is known as a 3.1-watt lamp. The specific consumption increases as the length of time that the lamp has been in service increases. For example, a lamp may consume but 3.1 watts per candlepower when new, and later, partly owing to a change in the filament and partly to the blackening of the globe, it may consume 3.8 to 4 watts or more per candlepower. A logical way of stating the efficiency of an incandescent lamp would be to express the candlepower given off per watt consumed, but this method is not in general use.

The amount of light given off by a lamp depends on the temperature at which the filament is worked; the hotter the filament, the greater the light-giving power per watt consumed. It is also true that the hotter the filament, the more rapidly will it change and lose its light-giving power. For this reason, low-efficiency lamps—3.5 to 4 watts per

candlepower—are usually longer lived than those of higher efficiency—3 to 3.1 watts. Lamps purchased for a certain candlepower and efficiency can be worked at higher values by increasing the voltage, but this will soon destroy the lamp. If used on a voltage lower than that for which they were intended, the lamps will give greatly decreased candlepower. Lamps are made for almost all voltages up to 250.

The new metallized-filament lamp and the metallic-filament lamps are capable of working at much higher temperatures, hence at higher efficiencies, than the carbon-filament lamps. The metallized-filament lamps are made for 2.5 watts per candlepower, and they maintain their life well. Some metallic-filament lamps consume only 1.25 watts per candlepower, with a longer useful life than the carbon-filament lamps.

12. Lamp Estimates.—With an average power consumption of 3.3 watts per candlepower, a 16-candlepower lamp needs $16 \times 3.3 = 52.8$ watts. The required current depends on the voltage at which the lamp is operated, and can be ascertained by using the following formula:

$$I = \frac{CP \times W}{E},$$

in which CP = candlepower;

W = watts per candlepower;

E = voltage across the lamp terminals.

Example.—A 32-candlepower lamp requires 3.5 watts per candlepower and is designed to operate at a pressure of 110 volts. What will be the current taken by the lamp and what will be the resistance of the lamp when hot?

Solution.—From the formula,

$$\text{current} = \frac{32 \times 3.5}{110} = 1.02 \text{ amperes, nearly. Ans.}$$

From Ohm's law, $I = \frac{E}{R}$, or $R = \frac{E}{I}$; hence,

$$\text{resistance} = \frac{110}{1.02} = 107.8 \text{ ohms. Ans.}$$

Note.—The resistance of an ordinary carbon lamp filament decreases as the temperature increases; the cold resistance may be almost double the hot resistance. In practical work, as a rule, when the resistance of an incandescent lamp is spoken of, the hot resistance is meant. A 16-candlepower 110-volt carbon-filament lamp has a hot resistance of about 220 ohms.

Small incandescent lamps require a larger number of watts per candlepower than large ones. For example, a 4-candlepower lamp requires in the neighborhood of 20 watts, or 5 watts per candlepower; 6-candlepower, 25 watts; 8-candlepower, 32 watts; and 10-candlepower, 37 watts. In general, the substitution of a small lamp for a larger one will result in a saving in power, but not in direct proportion. For example, if an 8-candlepower lamp is substituted for a 16-candlepower, the power consumption instead of being cut in half, might be reduced from about 52.8 watts to 32 watts.

13. Life of Lamps.—The term **useful life** of an incandescent lamp is generally understood to mean the period during which it will operate before its candlepower decreases more than 20 per cent. The length of life depends on the construction of the lamp, on the maintenance of the exact voltage for which the lamp was made, on the efficiency of the lamp, etc. Ordinary carbon-filament lamps have a useful life of about 500 to 600 hours.

14. Lamp Connections.—Two wires must connect to each incandescent lamp, whether the system is direct or alternating current. The lamps may be connected in series with one another or in parallel, but parallel connection is much the more common. Explanations of systems of distribution and lamp connections on direct-current systems are given in other Sections.

There are several systems of alternating-current distribution, known as *single-phase*, *two-phase* or *quarter-phase*, *three-phase*, etc. In general, these systems may be grouped in two classes, *single-phase* and *multiphase*, or *polyphase*, systems. **Single-phase currents** are produced by dynamos or alternators having only one set of coils on the armature and only two collector rings. Only two line wires are required.

15. Two-phase alternating currents are usually produced by alternators having two sets of armature coils so placed that when one set is generating maximum electromotive force, the other is moving through the neutral spaces

between the poles, and is therefore not generating. Such alternators usually have four collector rings, from which lead four line wires; that is, each set of armature coils supplies one circuit and the two circuits are entirely separated electrically from each other. Fig. 7 shows the method of

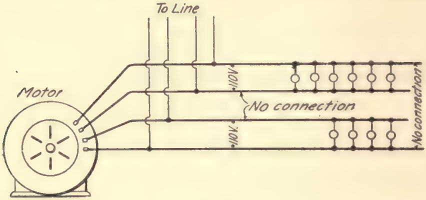


FIG. 7

connecting lamps and a motor to a two-phase four-wire system; all four wires lead to the motor, and the lamps are divided between the two phases. An effort should be made to divide the lamps so that the two phases will be equally loaded. The current in each of the four wires is one-half that which would flow in a two-wire circuit supplying the same total number of lamps.

The **two-phase three-wire system** is sometimes used, the two sets of coils on the alternator armature being con-

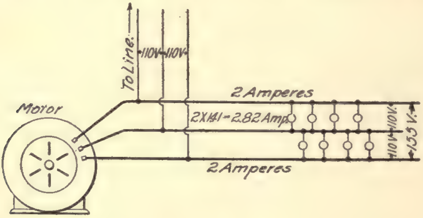


FIG. 8

nected at one end and a common return line wire being employed. Fig. 8 shows the method of connecting lamps and a motor to such a system, the middle wire representing the common return. The three wires lead to the motor, and

the lamps are connected between the common return wire and each of the others. It is essential that the current be the same in the two sides of this system; that is, the system must be balanced, otherwise poor voltage regulation and unsatisfactory lighting will result. When the system is balanced, the same current flows in each of the two outer wires, and the current in the common return wire is 1.41 times that in either of the outer wires. If the current in each outer wire is I, and that in the common return wire is I_m, then

$$I_m = 1.41 \times I$$

The common return wire should therefore be larger than either of the other two.

16. In the **three-phase system,** the alternator usually has three sets of armature coils spaced equally distant from each other on the armature core. These coils are nearly always so connected that only three line wires are necessary. The connections of a three-phase circuit to lamps and a motor are shown in Fig. 9. The voltage is the same between any two wires. All three wires run to the motor,

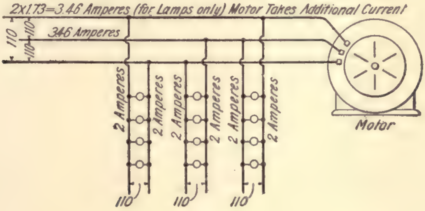


FIG. 9

and the lamps should be so distributed among the three phases that the circuit will be balanced. In some three-phase systems, where the current taken by the motors varies so much that the lights would be unsteady if the lamps were connected to the three wires, as shown in the figure, a fourth or neutral wire is installed for lamp connections only. One wire of each lighting circuit is connected to the neutral

wire and the other to one of the three-phase wires; the neutral wire is not connected to the motors.

In a **balanced three-phase three-wire system,** the current in any wire is 1.73 times the current taken from any phase of the system. Thus, if I_m is the current in one of the three wires and I_b the current taken from any phase,

$$I_m = 1.73 \times I_b$$

In Fig. 9, only one branch lighting circuit is connected across each phase, and the current taken from each phase is 2 amperes; hence, the current in each of the three main wires is $1.73 \times 2 = 3.46$ amperes.

At a given voltage and with a given line loss, the three-phase three-wire system requires only three-fourths as much copper to carry a given amount of power as the two-phase four-wire circuit; that is, each wire of the three-phase circuit is the same size as one of the wires of the four-wire circuit. Therefore, three-phase currents are more desirable for transmitting electric power long distances.

17. In a **single-phase system,** only two wires are necessary. Another system, known as the **monocyclic system,** which is sometimes installed, has two wires running to the lamps and three to motors, one of the three having no lamps connected to it. In any system, only two wires are needed at the lamp terminals; the main wires—two, three, or four, as the case may be—are brought to **distribution centers,** and two-wire circuits lead from the centers to the lamps. The calculations of wire for carrying alternating current to incandescent lamps are made the same as for direct current.

EXAMPLE 1.—If a center of distribution is supplied by a three-phase circuit, and from this center are led two-wire circuits to each of twelve clusters of lamps, each cluster requiring 3.5 amperes, how much current will flow in each wire of the three-phase circuit to the center, provided the lamps are equally divided among the three phases?

SOLUTION.—There must be four clusters across each phase, requiring $4 \times 3.5 = 14$ amperes from each phase. Applying the formula in Art. **16** and substituting for I_b its value 15,

$$I_m = 14 \times 1.73 = 24.22 \text{ amperes. Ans.}$$

EXAMPLE 2.—A large hall is lighted by fifty 32-candlepower 110-volt incandescent lamps. If 3.3-watt lamps are used and they are equally divided between two phases of a two-phase three-wire system, as in Fig. 8, what is the current in the middle wire?

SOLUTION.—By the formula of Art. **12**, the current required by the fifty lamps is $\frac{50 \times 32 \times 3.3}{110} = 48$ amperes. As but twenty-five lamps are on each phase, the current in each outer wire is 24 amperes, and by the formula in Art. **15**,

$$I_m = 24 \times 1.41 = 33.84 \text{ amperes. Ans.}$$

ARC LAMPS

THE ELECTRIC ARC

18. If a circuit in which an electric current is flowing is opened and the ends thus made are separated by a short gap, the current will continue to flow and will form a brilliant flame across the gap, accompanied by great heat. This flame is known as the **electric arc**, and is so called because it does not pass straight across, but follows a bow-shaped path. If the ends of the broken circuit consist of copper or iron, they will be rapidly melted, as sometimes happens to the contact points of switches. In most switches used for lighting purposes, however, the circuit is either opened so quickly that the arc is broken before it can seriously injure the contacts, or else some other provision is made for breaking, or suppressing, the arc.

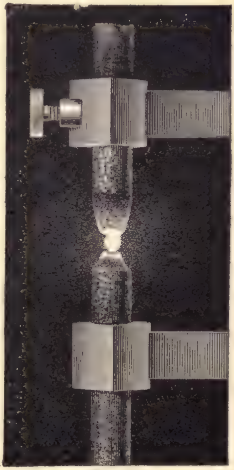


FIG. 10

19. Open Arcs.—In order to make the arc useful for light-giving purposes, a material must be used for terminals

that will not be too readily destroyed by the heat; carbon is the material mostly used. Fig. 10 shows an arc between the ends of two carbon rods. The intense heat vaporizes the carbon and the arc consists of incandescent carbon vapor, which conducts the current across the gap. The arc is on but a very small portion of the carbon tips at one time and shifts occasionally from point to point.

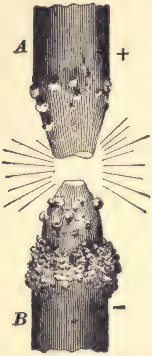


FIG. 11

Fig. 11 shows more clearly the shape assumed by the tips *in open air*. In the end of the positive carbon, which in most lamps is placed above the negative, a cup or *crater*, is formed; the negative carbon is pointed. This appearance of the tips will always indicate which way the current is flowing. The light comes from the vapor and the carbon tips, which are heated to incandescence. The positive carbon is much the hotter of the two, and the crater is the source of most of the light. With direct current, the positive carbon wastes away about twice as fast as the negative; with alternating current, which is very seldom used for open arcs, the rate of consumption of the two carbons is the same.


FIG. 12

20. Enclosed Arcs.—If an arc is maintained between carbon tips that are *enclosed* in a small chamber made *very nearly air-tight*, the tips will retain the shape shown in Fig. 12. The arc shifts gradually over the surface of the tips, but is always bow-shaped, as shown. The tips remain flat instead of taking the shapes of those in open arcs. The carbons are consumed very slowly, about .05 to .08 inch per hour, instead of $1\frac{1}{2}$ inches per hour, as with open arcs. The light is softer than that of the open arc, and, being enclosed, is much more appropriate for interior illumination. The enclosing globes

make the fire risk low, and the slow carbon consumption makes it possible for enclosed arcs to burn a long time without retrimming. Enclosed arcs operate very satisfactorily on either direct or alternating current, and both are used.

Enclosed arcs also require less current for the same watts input than open arcs; that is, they will operate with a higher voltage across the arc. The voltage across an open arc is usually from 35 to 45, while that across an enclosed arc is from 70 to 80.

ARC-LAMP CONSTRUCTION

21. An **arc lamp** consists essentially of an arc and a mechanism for maintaining the gap across which the arc occurs. As the length of the gap increases, the voltage required to force a constant current through it increases; or if a constant voltage is applied to the lamp terminals, increasing the length of the arc will cause a decrease in the current. In an arc lamp, these changes are taken advantage of to operate a system of magnets, which allow the carbons to approach each other when the distance between the tips becomes too great. The force of gravity is depended on to move the carbons toward each other. There are many types of arc lamps in commercial use. The principles of construction are the same in all, the differences being only in mechanical details.

CONSTANT-POTENTIAL LAMP

22. Constant-potential arc lamps operate in parallel across constant-potential circuits, each lamp independent of the others. The current through one lamp may increase or decrease as the length of its arc changes, or the circuit through the lamp may be opened without affecting the other lamps on the circuit. Fig. 13 shows a simple diagram of connections. Before the current is turned on, the carbons touch each other, so that the circuit through the lamp is complete. When the switch *m* is turned from the dotted-line position to the full-line position, current can flow from

the positive terminal t through the resistance r, the magnet S, the brush k, the brass rod e (called the carbon rod), the carbons g, h, and out at the negative terminal t'. If the connections are for a direct-current lamp, the direction of the current must always be as shown; that is, the positive carbon must be above. With an alternating current, it is immaterial which way the connections are made, as the current flows alternately in each direction.

When the switch m is first closed, the resistance through the lamp circuit is low, and there is a large rush of current for an instant, until the magnet S becomes energized and its

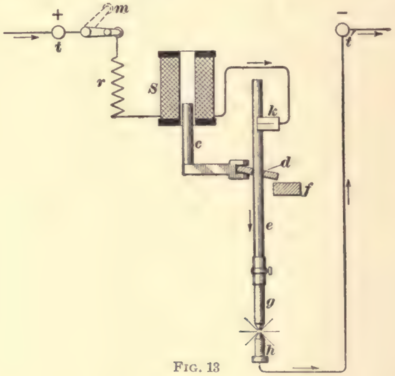


FIG. 13

core c is drawn up. This operation lifts the clutch d, which in this case is merely a washer with a hole just large enough for the carbon rod to slide through when the clutch is level or nearly so. As soon as one side of the clutch is raised, as shown in the figure, the carbon rod is gripped by it and raised, thus drawing the carbons apart, or *striking the arc*. The resistance of the arc limits the flow of current to an amount that will draw the magnet core c to the proper height to give the required length of arc; that is, a balance is reached and the arc continues to burn. As the carbon wastes away, the arc grows longer, its resistance becomes

greater, and the quantity of current becomes less. The pull of magnet *S* thus gradually decreases, and magnet core *c* settles until clutch *d* strikes the stop *f* and is brought toward a level position, permitting the rod *e* to slip down a trifle, which is commonly called *tripping the lamp*. As soon as the carbons approach each other, the flow of current increases, and *c* is again drawn up until the arc has the proper length. The resistance *r* takes up voltage not needed at the arc, and makes the action of the lamp stable.

CONSTANT-CURRENT LAMP

23. Constant-current arc lamps operate in series circuits, a constant current flowing through all the lamps in the circuits; each lamp is, in a measure, dependent on the other lamps in the circuit. The current through a single lamp cannot change, so the regulation is effected by means of the changing voltage across the arc as the length of the arc changes. A constant-potential lamp needs but one magnet, whose lifting power changes as the current through the lamp changes; a constant-current lamp must have one magnet in series with the arc for drawing the carbons apart, and one in shunt with it for regulating the length of arc. There are two classes of constant-current lamps: *differential lamps* and *shunt lamps*.

24. In a **differential lamp,** the ends of the carbons are in contact when the lamp is ready for service. Fig. 14 shows a diagram of connections. The switch *m* is arranged to short-circuit, or cut out, the lamp; it would not do to open the circuit through the lamp, as is done by the switch in a constant-potential lamp, as this, if it could be done, would put out all the other lamps in the circuit. As a matter of fact, it is very difficult to open a series-arc circuit; the attempt to do so results in furious arcing, and no ordinary switch will stand such usage. Magnet *S*, in series with the arc, exerts a constant upward pull on the core *c*, because the current through *S* is constant. Magnet *S'*, in shunt with the arc, draws the core downwards with a force depending

on the voltage across the arc. The adjustments are such that the forces exerted by the two coils balance when the arc is just the right length.

As the ends of the carbons burn away, the arc becomes longer and the voltage across it greater, thus forcing more current through magnet S', and increasing its downward pull until the clutch d is drawn down enough to allow the carbon rod to slip down a little. The arc voltage then immediately decreases, magnet S' weakens, and core c is again drawn upwards by magnet S.

If the carbons in a constant-current lamp burn out or anything else happens to interrupt its operation independently

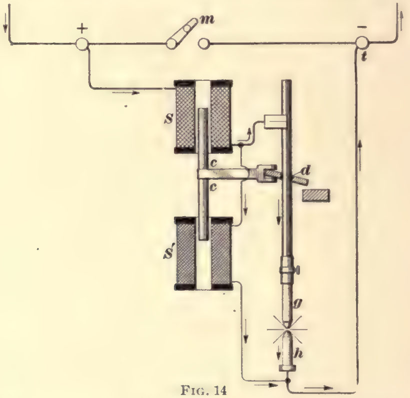
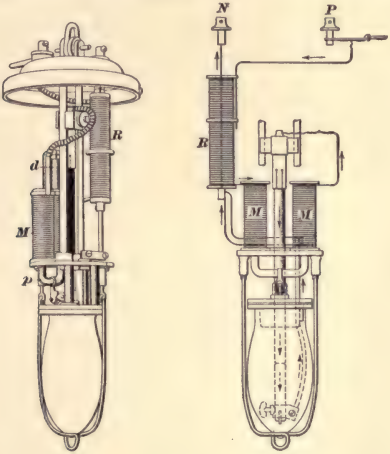


FIG. 14

of the other lamps in the same circuit, an **automatic cut-out** short-circuits the lamp so as to keep the main circuit continuous. This cut-out usually consists of a small magnet connected so that when the voltage across the arc becomes excessive and the tripping mechanism can no longer act, the cut-out magnet closes a short-circuiting switch.

25. When a **constant-current shunt lamp** is not in operation, the carbons are held apart by a spring or a weight. When the current is turned on, a series magnet releases the

clutch and allows the carbons to touch each other. This magnet is then immediately cut out of circuit by a small *starting magnet*, also in series with the arc. The spring then draws the carbons apart, thus establishing the arc. A third magnet, in shunt with the arc, then acts against the spring to draw the carbons together. The longer the arc becomes, the stronger the shunt magnet becomes, until it overcomes the spring and trips the lamp. The regulation is thus effected by a shunt magnet pulling against the action of a spring, instead of against a magnet in series with the arc.



(a) (b)

Fig. 15

The rapidity of the movements of the magnets in all types of arc lamps is usually dampened by the movement of a piston in a cylinder filled with oil or glycerine; that is, by a *dashpot*.

26. Constant-potential open-arc lamps are not much used. Constant-current open-arc lamps, however, have had very extensive use, mostly for outdoor illumination, and are still

to be found in many places; they are also used in some large interiors, though such use is not common. Constant-potential enclosed-arc lamps are much used for interior illumination. Constant-current enclosed-arc lamps are more appropriate for outdoor illumination, where the lamps are scattered over a considerable area, though they are sometimes used in interiors.

27. Enclosed-Arc Lamps.—The methods of operation of enclosed-arc lamps are essentially the same as those already explained, except that the clutch usually acts directly on the carbon, thus dispensing with the carbon rod. The current is led to the upper carbon through a flexible cable, so that no sliding contacts are required.

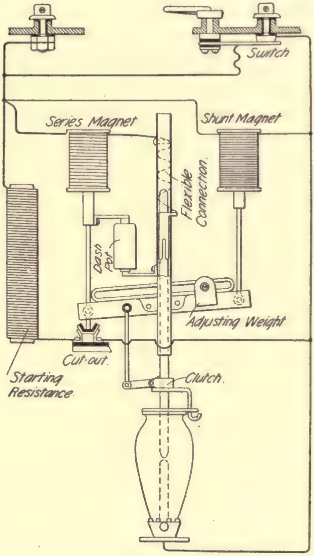


FIG. 16

Fig. 15 (*a*) and (*b*) shows two views of the interior arrangement of coils and connections in a **constant-potential enclosed-arc lamp.** Magnets *M*, *M*, in series with the arc, lift the **U**-shaped plunger *p* to which the clutch is attached, sudden movements being prevented by the dashpot *d*. An adjustable resistance *R* takes up the voltage not needed at the arc, thereby steadying the lamp and also permitting adjustments of the arc voltage. The connections, as shown in (*b*), will be readily understood. Small arrows indicate the path of the current from the positive terminal *P* to the negative terminal *N*.

28. Fig. 16 shows connections for an enclosed-arc lamp made for constant alternating current. The series- and shunt-magnet cores are attached to opposite ends of a rocker, one end of which is also attached to the clutch; the other end of the rocker bears a weight by which the arc voltage is adjusted. Each magnet consists of two coils in line with each other, so that only one of each shows in the figure. The figure shows the lamp ready for operation. When current is turned on, a portion of it goes through the starting resistance and the cut-out, and a portion through the shunt magnets; but the larger part goes through the series magnets, which lift the clutch, open the cut-out, and strike the arc. The balance is preserved by the two magnets, series and shunt, acting on opposite ends of the lever. When the arc becomes too long, the shunt magnet becomes stronger and draws up its end of the lever until the upper carbon slips through the clutch a short distance; this operation shortens the arc, decreases the voltage across it, and hence weakens the shunt magnet, permitting the series magnet to draw up its end of the lever and hold the carbons apart.

ARC-LAMP CIRCUITS

SERIES DISTRIBUTION

29. Arc lamps used for lighting widely scattered areas, as in street lighting, are nearly always of the constant-current type connected in series. Fig. 17 represents a series of direct-current arc lamps l, l, l connected to a dynamo A; t, t' represent lamp terminals, which are marked + and − to distinguish them from each other. If a lamp were connected backwards by mistake, as shown at B, the lower carbon would soon burn out and the arc would destroy the lower carbon holder. The current through all the lamps is the same, unless there is leakage across the lines at some place, as indicated from a to b. If the line wire is properly insulated, there will be little leakage; if great enough, the leakage decreases the current through the lamps around which it exists,

so that they would go out. As the lamps require but from 6 to 10 amperes, a small line wire answers; No. 6 or No. 8

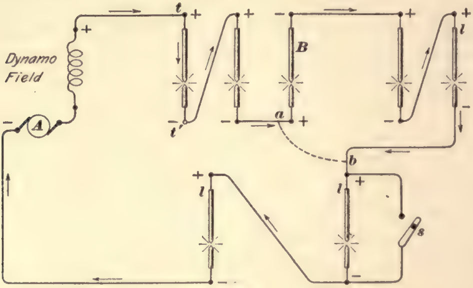


FIG. 17

B. & S. is generally used. Switch *s* indicates a method of cutting out one lamp; each lamp usually has such a switch.

30. Cut-Out Switches.—Fig. 18 represents a circuit of arc lamps in a large interior, the wires entering and leaving the building near one corner. The Fire Underwriters' rules require that wherever constant-current circuits enter and leave a building, as at *s*, an approved double-contact service switch shall be installed, so that current can be cut off at any time. These switches must be substantially made, must be mounted on incombustible bases, and must be placed where they can be easily reached by policemen

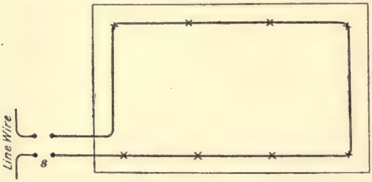
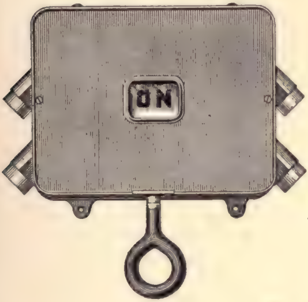


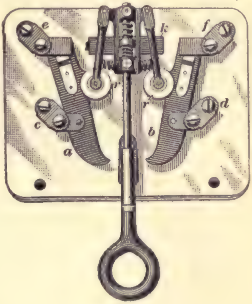
FIG. 18

or firemen. They must have good contacts; must close the main circuit and disconnect the branch circuit when turned off; must be automatic in action, not stopping between points when started; and must in all cases prevent an arc between points. They must also plainly indicate whether the current is on or off.

Fig. 19 shows a Wood arc cut-out, which is one of a number of types that conform to the Underwriters' requirements. This one will serve to illustrate the operation of arc cut-out switches in general. In (*a*) is shown the complete cut-out in a waterproof cast-iron box; it is operated by moving the handle up or down, the words "on" and "off" plainly indicating the connections. In (*b*) is shown the interior. The line wires connect to *c*, *d*, on which blades *a*, *b* are pivoted; the house wires connect to terminals *e*, *f*, which carry clips into which the pivoted blades are shown closed. By pulling down the handle, the rollers *r*, *r'* are drawn down



(*a*)



(*b*)

FIG. 19

below the pivots, when the springs cause the blades to fly out of the clips, thus disconnecting the house circuit from the line. Just before the blades leave the clips, they make contact with the casting *k*, thus keeping the main circuit closed. If the branch circuit were opened before the main circuit were closed, a furious arc would occur where the opening was made, and the switch would be destroyed.

31. Protection From Lightning.—As series arc-lamp circuits are usually much exposed, lightning discharges may sometimes follow the wires into a building or possibly enter the lamps and destroy the insulation of the coils. A lightning discharge will not go through a coil of wire if it can find a straighter path; in no case will lightning

follow the wire around a coil, but will jump across from layer to layer of the wire, thus destroying the insulation. To prevent this action a small spark gap, or **lightning arrester,** is sometimes connected across the lamp terminals. Fig. 20 shows a simple form of arrester consisting of two brass cylinders, one connected to each lamp terminal. The ordinary lighting current will not jump the gap between the two cylinders, but will go through the lamp. A lightning discharge, however, will jump across the gap instead of going through the lamp, and so passes on to the station, where it is diverted by the regular station arresters and sent into the ground.

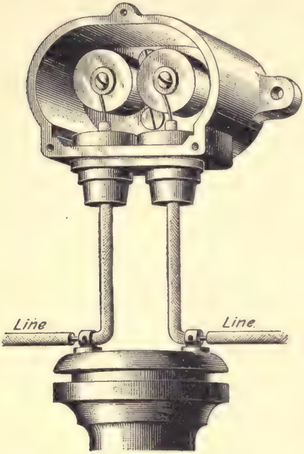


FIG. 20

PARALLEL DISTRIBUTION

32. When arc lamps were first introduced, **parallel distribution** was not very common; but owing to the increased use of enclosed-arc lamps for store and factory illumination where the high pressures necessary for series operation are very objectionable, many enclosed-arc lamps are operated in parallel on the constant-potential incandescent-lighting circuits. The lamps are connected as shown in Fig. 21, each lamp being provided with a double-pole switch, and a cut-out for protection in case of a short circuit in the lamp. The resistance shown is for regulating purposes and is mounted inside the lamp. The switch is also usually mounted in the top of the lamp and is arranged to open the circuit through the lamp, and not to short-circuit

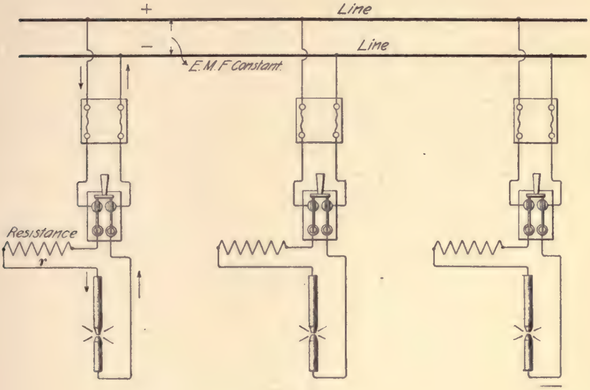


FIG. 21

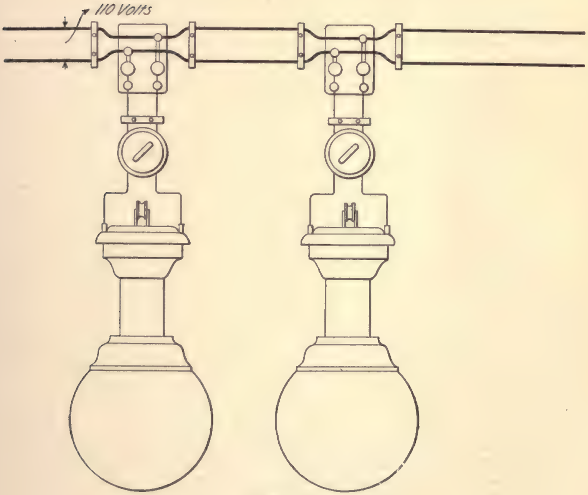


FIG. 22

it, as is done with constant-current lamps. Fig. 22 shows the lamp connections for a 110-volt direct-current system, and Fig. 23 the connections of alternating-current lamps to the secondary of a transformer.

33. 220-Volt Enclosed-Arc Lamps.—Enclosed-arc lamps for operation in parallel across 220-volt mains are

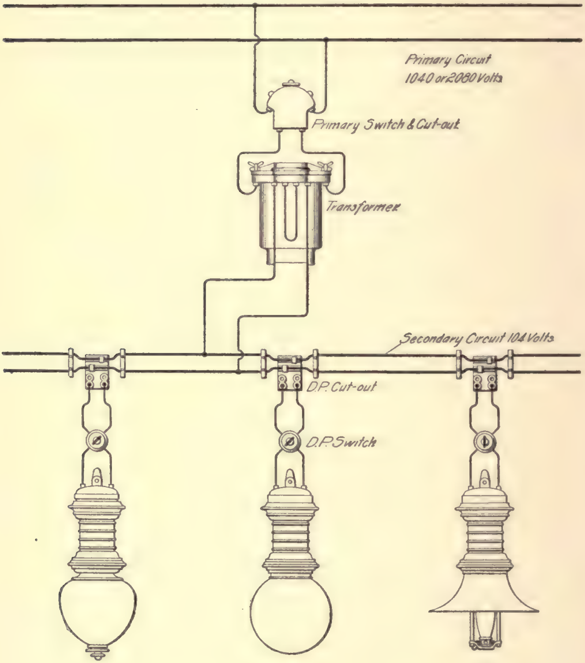


FIG. 23

built, but they are not quite so efficient or satisfactory as 110-volt lamps. They operate with about $2\frac{1}{2}$ amperes each and take 140 volts at the arc. Another type of 220-volt lamp consists of two 110-volt lamps combined in one; that

is, there are two sets of carbons and two arcs connected in series. Still another plan is to use two lamps in series across the circuit.

34. Enclosed-Arc Lamps on 550-Volt Circuits. It is very often desirable to operate enclosed-arc lamps on 550-volt railway circuits for the illumination of car barns, street-railway parks, etc. The special types of lamp made for this purpose are generally operated, five in series, across the circuit, so that each lamp receives, approximately, 110 volts. Each lamp is usually provided with a resistance in conjunction with an automatic cut-out, so that in case a lamp is cut out of circuit the remaining lamps will not get an excessive current and will burn uninterruptedly.

TESTING SERIES ARC-LAMP CIRCUITS

35. After the arc-lamp circuit of a building is complete, it should be tested for *breaks*, *grounds*, and *crosses*. None of these defects are likely to be found on a newly installed line if the work has been carefully done, but it is best to verify the perfection of the work by tests. There are several ways of making tests, but the most convenient test and the one most used is that made by means of an ordinary magneto-bell. This bell consists of an armature, having a single coil, which may be rotated by means of a suitable crank between the poles of a permanent magnet. The magneto generates an alternating electromotive force. Two bells are arranged so that if the circuit through the magneto armature and the bells is complete, the bells will ring. If the wiring job is to include hanging and connecting the lamps, the tests can be made after the lamps are in place and all connections made. If it is desired to test only the wiring, the ends of wire left for lamp connections may be temporarily connected together to make the circuit continuous.

36. Breaks.—When the magneto terminals are connected to the circuit terminals at the switch described in Art. **30**, a continuous circuit will be indicated by the bells ringing when the handle of the magneto is turned. If no

ring is obtained, the circuit is open; and if the break cannot be found by a simple inspection, further tests will be necessary. Let Fig. 24 represent a series-arc circuit in a large building. At some unknown place, as *x*, there is a break that prevents the bell from ringing when connected to the switch terminals *a*, *b*. To locate the break, ground the terminals *a*, *b*, as shown at *G*, by connecting to any convenient system of piping, and open the circuit at some point *c*, preferably near the middle. With one magneto terminal grounded, connect the other, first to one end of the circuit, as shown at *d*, and then to the other. A ring can be obtained through *d*–*l*–*l*–*a* and the ground, but not through the other side, because of the break at *x*. Close the circuit at *c* and move on to a place *f*, and repeat the same tests;

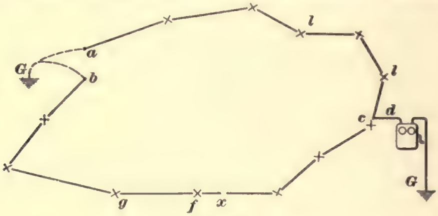


FIG. 24

this time a ring can be obtained through *f*–*g*–*b* and the ground, but not the other way, which shows that the break must be between *f* and *c*. By closing the circuit at *f* and opening it at some other point between *f* and *c*, the break can be still more closely located. When a break is traced to within a short length of wire, careful inspection will locate it. If there should be more than one break, the method of locating them will be the same, except that more tests may be necessary.

37. Grounds.—If a ring can be had when the magneto is connected between one end of the circuit and a steam or water pipe or anything in connection with the earth, the line is grounded somewhere. To locate this defect, leave the terminals out of the switch and entirely separate from each

other and from ground. Open the circuit at various points, testing between each terminal thus made and any convenient system of piping. In each case, a ring can be obtained only over that portion of the line which contains the ground. By repeating the tests at a few points, the ground can be located so closely that an inspection of the remainder will find it, probably, where the arc wire rubs against something or where a lamp is not properly hung.

38. Crosses.—There is so little chance for **crosses** to occur on a series-arc circuit in interior work that the necessity for tests will probably never arise. If a cross should occur, it will probably be due to grounds, and the ground test will apply. Any crossing of wires may be easily detected by inspection, as all series-arc circuits must be in plain sight.

ILLUMINATION OF INTERIORS

39. The subject of illuminating engineering has received greatly increased attention in recent years. In some of the older buildings the lamps seem to have been placed with a view of obtaining symmetry, ornamentation, economy in wiring, etc., rather than illumination where it is most needed. Electric lights and fixtures lend themselves so readily to ornamentation that it is not difficult to obtain excellent illumination without violating a taste for beauty; but, usually, good illumination should be the first consideration. Lamps should never be so placed that unbroken light rays fall directly into the eyes of observers; nor should there be a reflection or glare thrown back from the paper when reading or writing. The object should be to throw a soft and well-diffused light on the objects to be illuminated, and at the same time to shield the eyes. If, when looking directly at a light or at an object on which the light is turned, there are numerous streaks or a dazzling effect, the best results are not being obtained.

The proper selection of lamps and shades and the best location thereof for any given interior calls for very good

judgment on the part of an illuminating engineer or a wireman. Mills, factories, warehouses, stores, offices, and dwelling houses present in each instance a different problem, and probably in each no two rooms can be lighted in exactly the same way. The quantity of light required in a room will depend on the work to be done in it, on the size of the room, the height of the ceiling, and the color of the walls and ceiling, as well as the color of the furnishings or goods to be illuminated. If but few people are employed in a room, or if the work is of a coarse nature, less light is required than if many people are employed on fine work, such as sewing, reading, writing, etc. Ordinarily, a room with a low ceiling will require less artificial light than one with a high ceiling, but this is not always true. A room with light-colored walls, ceiling, and furnishings, or one in which light-colored goods are displayed, will require much less light than one in which all these are dark-colored. A room in which reading, writing, sewing, etc. is to be done, as well as stores where the goods are all displayed on tables, requires that most of the light be thrown from above toward the floors, and in some cases in somewhat concentrated locations, as in a reading room or library. A room containing wall pictures or goods displayed on the walls or on shelves, requires light thrown on the walls. Public halls, churches, etc., as well as parlors and sitting rooms, require a general illumination with the light so softened by shades that the eyes will not tire from continued use. Too much light has a blinding effect, so that it is often as objectionable as too little.

ILLUMINATION BY INCANDESCENT LAMPS

40. For lighting small rooms or for furnishing light to individual workmen whose work is confined to a comparatively small space, incandescent lamps are appropriate. They should be so placed and shaded that the work, and not necessarily the workman, will be illuminated. Fig. 25 (*a*) shows a peculiarly shaped lamp shade, and (*b*) shows its adaptability to one class of work; the workman's eyes are

completely shaded, but a bright light falls on the work. Show windows should be lighted by reflected light only, and the lamps should not be visible to observers. Theater lighting is nearly always produced by incandescent lamps; and as it is almost entirely for scenic effect, which depends on a careful adjustment of light intensities, experience is the

FIG. 25

only guide. Ordinary house lighting by electricity is done altogether with incandescent lamps, and appearance or effect must be kept nearly as much in view as illumination.

41. The light given by a standard candle at a distance of 1 foot is called a **candle-foot** and is a good light to read by. The degree of illumination on any object is usually

expressed in candle-feet. The intensity of the illumination produced by a concentrated source of light on any object decreases as the square of the distance of the object from the source of light increases. For example, if a lamp gives 16 candle-feet at a distance of 1 foot, it will give 4 candle-feet at a distance of 2 feet, and only 1 candle-foot at a distance of 4 feet. If B is the candlepower of a concentrated source of light and D is the distance in feet of the object from the source, then the illumination in candle-feet

$$C = \frac{B}{D^2}$$

EXAMPLE.—What will be the illumination, in candle-feet, produced by a 32-candlepower lamp placed 9 feet from the object illuminated?

SOLUTION.—Here $B = 32$ and $D = 9$; applying the formula,

$$C = \frac{32}{9 \times 9} = .395 \text{ candle-feet, approximately. Ans.}$$

The illuminating value of different lights is about as given in Table I. A clear idea of these intensities will be gained when it is remembered that 1 candle-foot is a good light to read by.

TABLE I

ILLUMINATING VALUES

Light	Candle-Feet
Ordinary moonlight	.025
Street lighted by gas	.030
Stage of theater	2.9 to 3.8
Diffused daylight	10.0 to 40.0

42. Quantity of Light.—The quantity of light required in a room depends on many varying conditions, among which are the purpose for which the room is to be used, the color of the walls, ceiling, and furnishings, the shape and height of the ceiling, etc. For example, a brilliantly lighted ball-room requires more light than a hall; a room with dark-colored walls and ceiling, or with a vaulted or paneled ceiling,

requires more light than one in which all these reflecting surfaces are light tinted and the ceiling smooth and horizontal.

For ordinary rooms with 10-foot ceilings, the installation of from .25 to .29 candlepower for each square foot in the floor or ceiling will give a good general illumination, provided the walls and ceiling are not too dark. For example, a parlor 12 ft. × 14 ft. and 10 feet high should have about three 16-candlepower lamps, making $\frac{3 \times 16}{12 \times 14} = .286$ candlepower per square foot of floor area. If the ceilings are higher, or if a brilliant illumination is desired, or if all the reflecting surfaces in the room are dark-colored, from .45 to .5 candlepower per square foot may be required. Ballrooms, reception rooms, picture galleries, etc. sometimes have 1 candlepower per square foot. On the other hand, such places as reading rooms and sewing rooms, requiring good illumination only in concentrated locations, may have far less total light in a room than is indicated by the foregoing figures.

43. Reflectors, Shades, and Globes.—On looking for a moment at the glowing filament of an incandescent lamp, the eyes become so dazzled that nothing else can be seen until the sight has been readjusted. Unshaded clear-glass bulbs are therefore unsuitable for work that is trying to the eyes. Frosted lamps so break up and diffuse the light rays that the bulb itself seems to be the source of a light much softer and less trying than that from the filament. Less total light is thrown out from a frosted-bulb lamp than from a clear one; but on account of its better diffusion, the smaller quantity is often the more useful. It may also happen that a large part of the light from a lamp is wanted in but one locality, as over a desk or reading table, very little being needed elsewhere.

Lamp reflectors, shades, and **globes** may be used for either of these purposes; namely, to soften and diffuse the light or to direct it to one location. They are also used sometimes purely for ornamental purposes, and should be carefully selected for the purpose required.

44. Fig. 26 shows the difference in distribution obtained with two glass shades that have very much the same general appearance. The shades are known by the trade name Holophane; they have pressed in their outer surfaces prisms that reflect and diffuse the light so as to greatly soften it. Differences in the shape of the prisms as well as the slight difference in the general form of the shades cause the difference in the light distribution.

The lamps in both cases are 16 candlepower and have frosted bulbs. In (*a*), 13.3 candlepower is thrown off at an angle 15° below the horizontal, and 41.9 candlepower directly

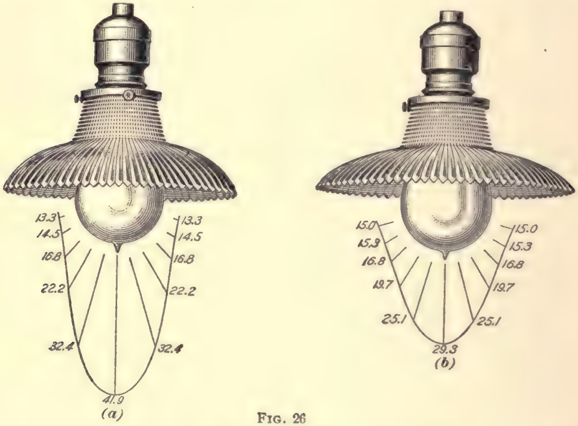


Fig. 26

downwards. In (*b*), the corresponding values are 15 and 29.3, respectively. The shade shown in (*a*) is appropriate for concentrating the light, and that in (*b*) for distributing it. Both shades throw nearly all the light below the horizontal instead of permitting it to be thrown on the ceiling, where, in most cases, it would be useless. Without a shade, the light given off by a 16-candlepower frosted lamp is about as shown in Fig. 27. By comparing corresponding values of Figs. 26 and 27, the effect of the shades will be more striking.

The two shades shown in Fig. 26 are merely illustrative of the use of shades in general, and do not represent the

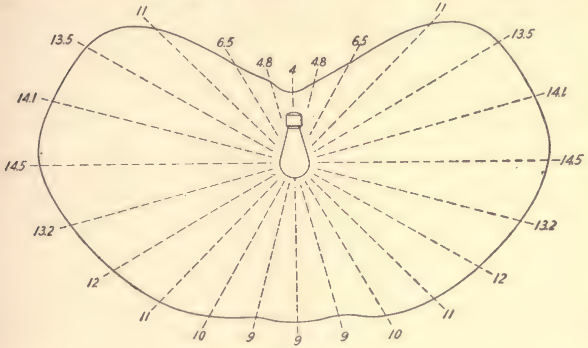


FIG. 27

extremes either of concentration or of distribution that may be obtained with other shapes.

45. High Candlepower Lamps.—In order to meet the demand for a lamp with illuminating capacity intermediate between that of the ordinary incandescent lamp and the arc lamp, the General Electric Company has brought out an enlarged incandescent lamp with a suitable reflector; this is called the meridian lamp. Fig. 28 shows the appearance of size No. 2. The light is practically all distributed in a hemisphere below the lamp, and the illumination under the lamp of a circular area having a diameter equal to the height of the lamp above it is equivalent to that produced by a 50-candlepower lamp. The distribution is represented by the curve in Fig. 29, which

FIG. 28

indicates that the illumination in a moderate-sized room

with such a lamp suspended near the center of the ceiling would be very uniform. The lamp consumes 120 watts. The same company is offering a high-candlepower high-efficiency lamp using the new metallized filament. These lamps are

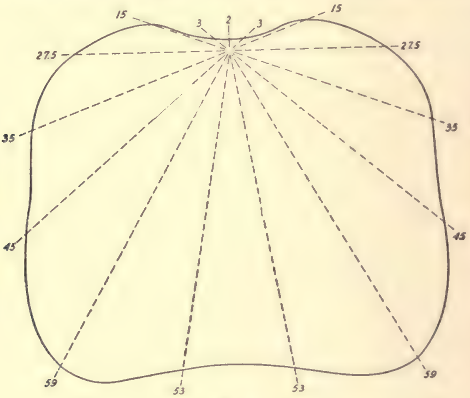


FIG. 29

also fitted with Holophane shades, giving them very much the appearance of those shown in Fig. 26. The globes of all these high-candlepower lamps are frosted, thus making the light agreeable.

ILLUMINATION BY ARC LAMPS

46. Mills, factories, stores, halls, etc. can often be most satisfactorily lighted with arc lamps. Open-arc lamps are sometimes used for such work; but the light from enclosed-arc lamps is more steady and agreeable, and if the lamps are provided with light opal globes or reflectors, a very even illumination can be obtained. Table II shows the approximate number of watts per square foot of illuminated floor area required at lamp terminals for first-class illumination. These figures are for arc lamps producing 1 candlepower for each 2 or 2.5 watts consumed.

TABLE II

WATTS PER SQUARE FOOT FOR INTERIOR ARC LIGHTING

Building	Watts per Square Foot Average Conditions	Watts per Square Foot Variation
Machine shops, high roofs, no belts	.75	.50 to 1.00
Machine shops, low roofs, belts, and other obstructions	1.00	.75 to 1.25
Hardware and shoe stores	.75	.50 to 1.00
Department stores, light material, bric-à-brac, etc.	1.00	.75 to 1.25
Department stores, colored material	1.25	1.00 to 1.50
Mill lighting, plain white goods	1.10	.90 to 1.30
Mill lighting, colored goods, high looms	1.30	1.10 to 1.50
General office, no incandescents	1.50	1.25 to 1.75
Drafting rooms	1.75	1.50 to 2.00

LIGHT DISTRIBUTION FROM ARC LAMPS

47. The light given out by an arc lamp is not so uniform as that from an incandescent lamp. The kind of current, whether direct or alternating, the position of the arc in the lamp, as well as its position relative to the carbon tips, affect the light distribution. An alternating-current arc has a small crater in each carbon tip, so that a larger portion of the light is thrown upwards than from a direct-current arc. When a lamp is first trimmed, the arc is in its highest position, and when nearly burned out, it has settled to near the lower carbon holder, thus increasing the shadow caused underneath the lamp by the lower carbon holder or the lamp bottom. While the lamp is in operation, the arc is continually shifting from point to point on the carbon tips, thus changing the direction of maximum light.

In order to make the distribution of light more uniform, globes are used around the arcs. These globes cut off a

portion of the total light, but they distribute what passes through them more evenly over the surfaces to be illuminated. Clear glass globes, generally used on open-arc lamps for outdoor lighting, cut off from 6 to 10 per cent. of the light; opal globes, much used on open-arc lamps in interiors, absorb from 30 to 60 per cent. of the light, according to the degree of milkiness of the globe; porcelain globes, also sometimes used for interior lamps, absorb over 50 per cent. of the light. Enclosed-arc lamps for outdoor work have both an inner and an outer enclosing globe; but for interior work, the outer globe is usually replaced by a shade, especially for alternating-current lamps.

48. The distribution of light around a direct-current open-arc lamp with the arc exactly in the center of the carbons is about as shown in Fig. 30, in which the areas

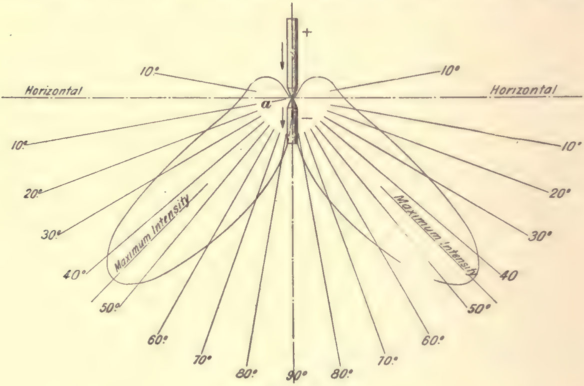


Fig. 30

receiving the larger portion of the light are enclosed by irregular curved lines. If the arc shifts to one side, the area on that side will increase and that on the other side will decrease. Comparatively little light is thrown off in a horizontal direction, the major portion going off at an angle of 45° downwards from the horizontal, or in the direction most

useful for street lighting. The area directly under the lamp is in comparative shadow, but this shadow can be largely dispelled by using an opal or a porcelain globe, which breaks up and distributes the light rays.

Fig. 31 shows the approximate distribution from one side of an alternating-current open-arc lamp. There is a large amount of light thrown upwards at an angle of about 50° from the horizontal, which makes it necessary to use a shade or diffuser. Such lamps are nearly always of the enclosed-arc type. The figure is used merely for comparison with the distribution from a direct-current open-arc lamp, as shown in Fig. 30.

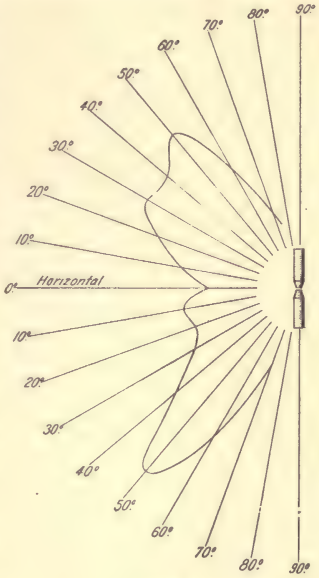


FIG. 31

49. Direct-Current Enclosed-Arc Lamps. The data for the curves in Fig. 32 are abstracted from a report of a committee of the National Electric Light Association on tests made by C. P. Matthews. Each curve shows the average of curves from direct-current 110-volt enclosed-arc lamps used on constant-potential circuits. Curve A shows the distribution with an opalescent inner globe and no outer globe. This curve should be compared with that in Fig. 30 for open-arc lamps. The light from the enclosed-arc lamp is not so intense as that from the open-arc lamp, but is more evenly distributed. Curve B shows the distribution when a clear outer globe was used with the opalescent inner globe.

and curve *C* that with opalescent inner and outer globes. Both outer globes have the effect of cutting down the intensity of light and of slightly changing its distribution.

The distribution of light from an enclosed-arc lamp is subject to considerable variation, and depends to some extent on the shape of the enclosing globe and on the thickness of deposit on it; also on the position of the arc in the enclosing globe.

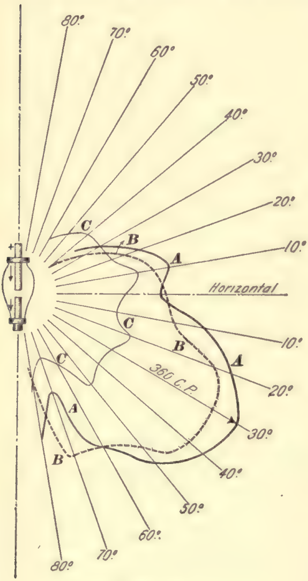


FIG. 32

50. Alternating-Current Enclosed-Arc Lamps.—The curves in Fig. 33 show the approximate distribution from an alternating-current enclosed-arc lamp with an opalescent inner globe. Curve *A*, taken with a clear outer globe, shows a large quantity of light thrown above the horizontal; curve *B*, taken with an opalescent outer globe, shows considerably decreased light and slightly changed distribution; curve *C*, taken with a reflector, or reflecting shade, shows greatly increased light below the horizontal, though still not equal to the downward light from the direct-current enclosed arc, as shown in Fig. 32.

51. Concentric Light Diffusers.—In order to reduce the effect of the extreme brilliancy of arc lamps and to throw on surrounding objects a soft, even illumination, free from strong light contrasts and deep shadows, many forms of reflectors and shades have been used, one of these being the

concentric light diffuser made by the General Electric Company. In Fig. 34 (*a*) is shown a lamp equipped with a concentric diffuser and a lower shade, while in (*b*) is shown how all the light rays thrown upwards from the arc are reflected in a downward direction. Other light rays, not shown, are thrown downwards from the arc and are broken up by the lower shade, so that the diffuser and the shade seem to be the source of a soft, easy light.

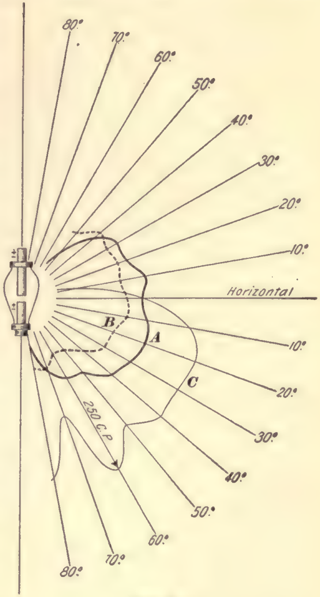


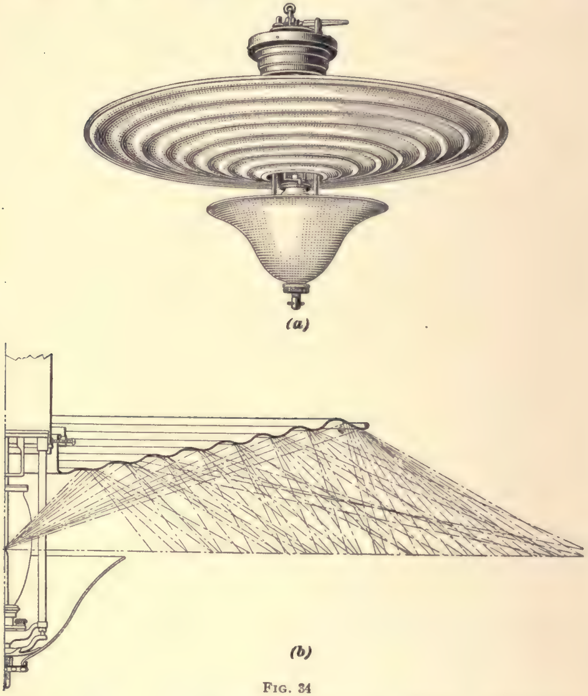
FIG. 33

The concentric-diffuser principle has also been applied to the ceilings of some large stores. The ceilings are made of special form with provision for concealing from view all but the lower shades of the lamps. All the useful light thrown against the ceiling is reflected on objects below, thus producing a light very nearly equal to daylight. Fig. 35 shows a portion of a selective-diffuser ceiling with one lamp.

RATINGS OF ARC LAMPS

52. Candlepower.—On account of the changing conditions in an arc lamp, it is difficult to measure the candlepower. Arc lamps are usually compared in terms of their mean spherical candlepower, although this term is of little use to a customer that desires light only in certain directions.

The 9.6-ampere direct-current open-arc lamp formerly rated at 2,000 candlepower probably gives about 375 to 450 mean spherical candlepower, and that rated at 1,200 candlepower probably gives about 250 to 300. The mean spherical candlepower of curve *A*, Fig. 32, is about 223; curve *B*, 181;



(a)

(b)

FIG. 34

curve *C*, 155. For alternating-current lamps, represented by Fig. 33, the mean spherical candlepower for curve *A* is about 140, and for curve *B*, 114.

53. Efficiency.—A 9.6-ampere constant-current open-arc lamp requires about 1.2 watts per spherical candlepower.

A direct-current enclosed-arc lamp requires about 1.8 watts per spherical candlepower, not counting the loss in the regulating resistance. Constant-potential lamps operated in parallel must have a resistance in series, which may absorb 140 or 150 watts. Including this loss, the power consumption per spherical candlepower will be from 2.3 to 2.4 watts. For example, the lamp from which data for the curves in Fig. 32 were obtained took 4.9 amperes at 110 volts, or 539 watts, of which 147 watts was used in the resistance and 392 at the arc. Curve *A* represents 223 mean spherical candlepower; hence, the total number of watts per candlepower was

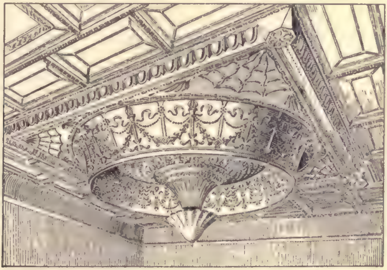


FIG. 35

$539 \div 223 = 2.4$. Excluding the loss in the resistance, the watts per candlepower at the arc was $392 \div 223 = 1.8$, nearly.

A constant-potential alternating-current lamp is regulated by means of a coil of wire called a *reactance*, or *choke coil*. The loss in this coil is much less than that in the regulating resistance of a direct-current lamp. Including the loss in the choke coil, a constant-potential alternating-current arc lamp consumes about 2.45 watts per spherical candlepower. If a reflecting shade is used to throw all the light into the lower hemisphere, the consumption per candlepower of useful light is much less than 2.45 watts.

ELECTRIC-RAILWAY STATION EQUIPMENT

(PART 1)

GENERATING APPARATUS

MECHANICAL EQUIPMENT

1. One of the first problems that confronts the electric-railway engineer is the production of energy for driving car motors. If, within the distance over which direct current at working pressure can be economically transmitted, there is available an abundant and reliable water-power, this will naturally be his choice for driving the generators. Even if alternating current must be transmitted a considerable distance at high pressure, transformed down, and converted to direct current, the wisest choice may still be water-power, if it is available.

In by far the larger number of electric-railway stations, the prime movers are probably steam engines, steam turbines, or gas engines. Formerly, steam engines have been used almost exclusively; but improvements have been made in steam turbines and gas engines that make them strong competitors of the steam engine. Some very important installations of steam-turbine and gas-engine power plants have been made, and others of still greater magnitude are under way. On account of the limited use of water-power for the operation of electric railways, nothing will be added to what was said concerning it in *Electric Transmission.*

The scope of this Section will permit only a general outline of the mechanical equipment of a railway station, together with a brief reference to each of the most important parts. A logical order for considering steam-power stations is to trace the various processes by which the latent energy in the coal is converted into the electric energy supplied to the working circuit.

STEAM BOILERS AND ACCESSORIES

2. Boilers.—In a **steam boiler**, the heat given off by the combustion of coal is made to strike against iron plates, which readily conduct it through to the water lying against the other side. The heat passes into the water and converts it into steam. The smaller the quantity of water per unit area of plate, the more rapid the conversion; hence, in order to obtain a large heating surface within a limited space, the plates are made in the form of tubes, which carry either the water, forming *water-tube boilers*, or the hot gases, forming *return-tubular*, or *fire-tube*, *boilers*. In the former, the hot gases circulate around and among the tubes within the boiler shell, and in the latter the water is contained within the shell, and the tubes carrying the hot gases pass through the water.

For railway stations, the choice between the two types of boilers rests on very much the same grounds as already given for electric transmission and lighting. On account of safety and quick-steaming facilities, water-tube boilers are perhaps favorites for railway stations, though both types are used. Each type of boiler is made for horizontal or vertical operation, the latter method being adopted where floor space is limited.

3. Location and Setting of Boilers.—The loss of heat by radiation to the atmosphere is decreased by encasing the boiler with brickwork or stonework; this casing, together with the foundations on which the boiler rests, is called the **boiler setting.** The boilers should be located as near

as possible to the engines they are to supply, but the boiler room and the engine room should be separated by a fire-wall. There should be space enough at the ends of the boiler to permit withdrawing and renewing the tubes, and an air space should be left between the sides of the boiler and the walls of the building. Water-tube boilers are usually grouped in batteries of two, so that each boiler may be inspected from the side, but a larger number of fire-tube boilers may be set side by side.

4. Labor-Saving Devices.—The cost of labor is one of the chief items in the operation of a power station. In order to reduce this expense, many power stations, especially the larger ones, have adopted mechanical devices, known as **conveyers,** for handling coal and ashes. The coal conveyer is usually arranged to take coal directly from a car or a barge and carry it to the coal bunkers above the boilers. The ash conveyer runs along under the ash-pits, so that, as the ashes are dumped down, they are carried out. In small plants, conveyers are not always provided, because the amount of coal and ashes to be handled is comparatively small, and the employment of conveyers would not reduce the number of men needed.

To reduce the labor of hand firing, **automatic stokers** are sometimes used, so that in some large stations no shoveling is necessary. The coal is fed from the bunkers through chutes into hoppers in front of the boilers, and from the hoppers it is automatically carried, as needed, on to the grates.

5. Water Supply.—If the water used to feed boilers contains certain impurities, they will adhere to the heating surfaces in the form of a hard crust, known as *boiler scale.* This scale may become so thick as to interfere seriously with the absorption of heat by the water and may cause the boiler plates to be burned. With very poor feedwater, modern stations use a water purifier, which removes a large portion of the impurities before they get inside the boiler where they can work injury. The purification is sometimes

done by a chemical process and sometimes by heating the water until the impurities are precipitated on the surfaces in the heater, from which the scale can easily be removed.

6. Heating Feedwater.—Before water can be converted into steam, it must be brought to a temperature corresponding to the steam pressure. The higher the pressure, the greater the quantity of heat necessary to be supplied to the water. There is a large quantity of heat wasted about every boiler plant. It is not possible to utilize all the waste heat, but much that would otherwise go out with exhaust steam or that would go up the chimney with the waste gases can be used to heat the feedwater. The processes of feedwater heating and purifying are often combined in one, the exhaust steam being led into contact with the feedwater, which is thereby heated and its impurities expelled before the water enters the boiler.

An arrangement by which the feedwater is led through coils of pipe around which the hot flue gases pass on their way from the boiler to the chimney is called an **economizer.** The water must either pass through exhaust heaters and purifiers or be treated chemically before passing into the economizer, otherwise scale will form inside the economizer tubes.

7. Feeding Water to the Boilers.—The pressure on the feedwater must be raised above that inside the boiler before water will flow into the boiler; this is usually done by pumps, which may be driven by gearing direct to an engine or to an electric motor; direct-acting steam cylinders are sometimes used to drive the feed-pumps. Geared pumps, however, are the most economical. An apparatus called an *injector*, in which a jet of steam acting on a jet of feedwater forces it into the boiler, is sometimes used.

STEAM ENGINES AND ACCESSORIES

8. Types of Engines.—Engines are classified according to their position as *vertical engines*, which occupy comparatively little floor space and hence are much used where

real estate is valuable, and *horizontal engines*, which are more easily observed when in operation and more accessible for repairs. As to speed, there are *high-speed engines*, which have close speed regulation under varying loads, and *low-speed engines*, which require less attention and less expense for repairs and adjustments. Between these two is a class sometimes known as *medium-speed engines*. As to method of operation, there are *simple* and *compound engines*, according to the number of cylinders in which the steam is expanded; also *condensing* and *non-condensing engines*, according to whether the exhaust steam is, or is not, discharged into a condenser.

9. Selection of Engines.—In addition to the reasons already given for the selection of high-speed automatic engines for small plants with widely fluctuating loads, it should be noted that such engines are more suitable for direct connection to generators than are those of lower speed, because the higher the speed of rotation at which a reciprocating engine can be safely made to run, the less the first cost of both engine and generator. On account of the close daily attention required by high-speed engines, some stations use slower speeds and, if floor space is not too expensive, belt direct from the engine flywheel to the dynamo pulley. In older stations, the engines were sometimes connected to countershafts, on which were carried large pulleys that could be thrown in or out by means of clutches. The large pulleys were belted to the dynamo pulleys. With this arrangement, any dynamo could be driven by the engine at either end of the countershaft.

Countershafts are no longer used to any extent in railway plants, the tendency being rather to split the station into a number of distinct units. When the units are very large, and also if the space is limited, direct-connected engines and dynamos are preferable. In some of the largest stations, vertical Corliss engines are used, and these are generally of the compound or the triple-expansion type. The first cost of a direct-connected dynamo is greater than a belted one for

the same output, but the saving in space and the absence of belts go far to compensate for this item and account for the rapidly increasing use of direct-connected units. When this class of machinery was first used, trouble was caused in some instances by magnetism leaking to the shaft and bearings in such a way as to cause a lateral thrust on the shaft and give rise to hot bearings. In the later styles of machines, however, this trouble has been almost wholly avoided.

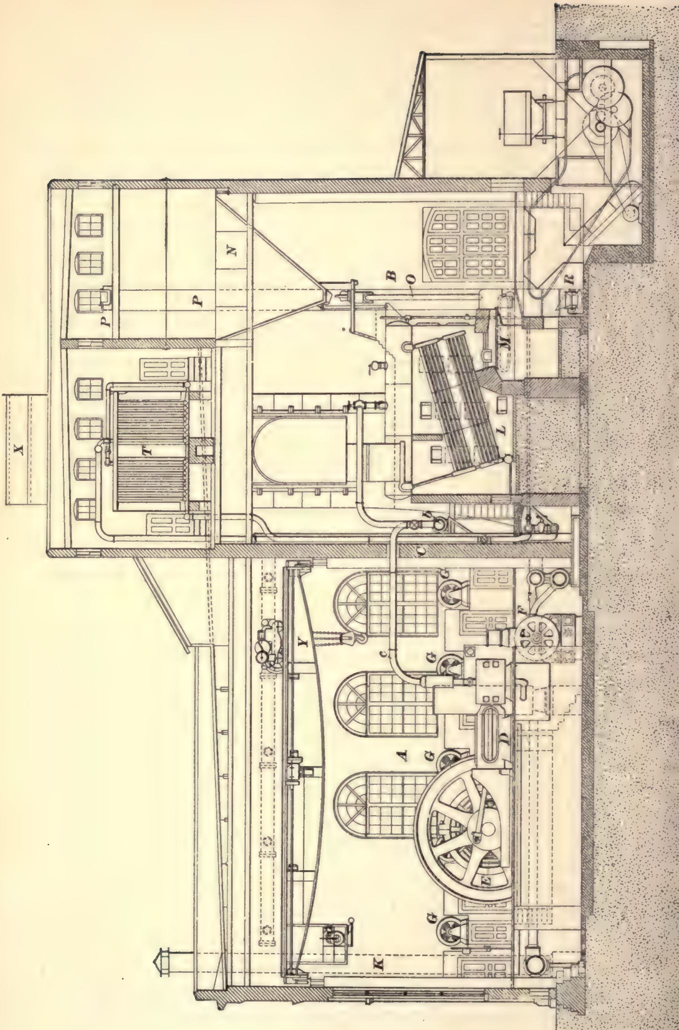
An objection to direct-connected units in electric-railway work is the fact that they receive greater shocks from sudden overloads. The steam and electric units are rigidly connected, and the flywheel and the dynamo have great inertia, so that, in case of an excessive overload, there is nothing to finally relieve the stress on the dynamo should the circuit-breaker fail to open the circuit at once. With a belted unit, an excessive load causes the belt or the clutch to slip, and thereby act as a kind of mechanical safety device to cushion the shock. On the whole, however, everything is in favor of the direct connection, due precautions being taken to see that the circuit-breaker is set at a safe load and that it works promptly at this load. Generally speaking, very heavy flywheels should be used on engines for running street railways. The whole engine construction must be of a very substantial character, because the load is liable to severe fluctuations.

10. Size of Engines.—The size of engines and dynamos for different station units depends on the total output of the plant and on the daily load distribution, or *load factor*. It is not a good plan to have a large number of small units, because they are not as efficient as larger ones; nor is it economical to have only one or two large units, because under such circumstances, at certain hours of the day when traffic is very light, even if only one of these units is operated, it runs at much below its full capacity, and hence operates at a low efficiency. The units should be arranged so that they may be kept loaded up to nearly their full capacity. In most of the modern plants the units are of the same size and type,

because a small stock of repair parts is then sufficient for the station. It is always an advantage to have the machinery in a station uniform, even if a few advantages in other directions have to be sacrificed to attain this end.

11. Steam Piping.—What has been said about steam piping for transmission and lighting plants applies also to electric-railway stations. The aim should be to secure reliable service with economical construction and low transmission loss. In a successful station there should be no shut-downs due to preventable accidents or failures. To make the steam-transmission losses low, the pipes and fittings must be so proportioned as to permit a free flow of steam and water. The piping should be so arranged that all water of condensation will return to the boiler. With modern fittings and methods of working, duplicate piping is not necessary. Allowance must be made for expansion and contraction without straining any part of the system; pipe bends with long radii will provide for much of this.

12. Condensers.—When an engine exhausts into open air, there is always a back pressure equal to the atmospheric pressure plus whatever loss of pressure may be caused by the steam passing the ports, or openings, from the cylinder. By passing the steam into a closed chamber and there condensing it, a partial vacuum is created, because the water of condensation occupies but a minute portion of the space occupied by the steam. A pump arranged to withdraw water, air, vapor, etc. from the chamber makes the vacuum more nearly perfect, so that almost all of the back pressure can be removed, leaving the effective pressure on the engine piston that much increased. Such an apparatus is called a **condenser.** If the exhaust steam strikes against the surface of pipes that have cold water circulating inside, the apparatus is known as a **surface condenser.** If a jet or spray of cold water is brought into contact with the exhaust steam, a **jet condenser** is formed. By means of a grease extractor, the oil can be removed from the exhaust steam, so that with a surface condenser the pure distilled water of



condensation already heated is available for feedwater. Pure water, however, is a solvent of iron, so a small quantity of fresh water is always mixed with the water of condensation before pumping it into the boilers. The jet condenser is somewhat less complicated and expensive than the surface condenser and occupies less floor space; hence, it is often preferred, even though the hot mixture of condensed steam and condensing water may in some cases run to waste.

13. Cooling Towers.—In stations located where the water supply is limited or where the purchase of water for condensing purposes would be expensive, **cooling towers** are used. These towers are made in various ways, but in most cases the water is exposed to the air and cooled by allowing it to drop from the top of a tower in thin sheets. Sometimes, the water is allowed to drop through a current of air set up by a fan, in which case a shorter tower can be used. In either case, the comparatively rapid evaporation of the water results in its being cooled enough so that it can be used over again.

14. Example of Station.—Fig. 1 shows a cross-section of the power station of the South Side Elevated Railway Company, of Chicago. This station, like nearly all power houses, consists of two large rooms—the engine room *A* and the boiler room *B*—separated by a brick fire-wall *C*. Each of the engines *D* is of the horizontal cross-compound Corliss type and is coupled directly to its dynamo *E*. These engines are rated at 1,200 horsepower each; they can, however, develop 2,000 horsepower, if necessary. The dynamos are of 800 kilowatts capacity and have twelve poles; they will also stand heavy overloads without damage. The exhaust steam from the engines passes to an independently driven jet condenser *F*, and the condensing water is cooled by means of a cooling tower placed outside the building. The cooling tower is divided into sections, and each section is provided with fans driven by the motors *G*, which are inside the building. If necessary, the engines may be allowed to exhaust into the air through the pipe *K*. The boilers *L* are

of the water-tube type and are fed by chain-grate stokers *M*. Coal is supplied to the boilers from the bunkers *N* through the chutes *O*. The bunkers have a storage capacity of 1,000 tons, and are filled by means of the conveyer *P*, which carries a continuous chain of buckets and passes up the side of the plant, across over the bunkers, down the other side of the plant, and along under the ash-pits, thus forming a continuous chain. The coal is delivered to this conveyer by a second conveyer *R*, which takes it from a car. A fuel economizer *T* is used, so that the hot gases on their way to the stack *X* may be used to heat the feedwater. All the steam pipes from the boilers run to the main pipe *b*, from which steam pipes *c* run to the different engines. The dynamo room is provided with an overhead electric traveling crane *Y*, to be used in placing or repairing the engines and dynamos.

OTHER PRIME MOVERS

15. Steam Turbines.—In a **steam turbine,** the energy stored in the steam is converted into rotary motion by causing steam jets to act on vanes, or buckets, carried on a wheel. Within recent years the steam turbine has been brought to a high state of perfection. For best results, a high speed is necessary, thus requiring either speed-reducing mechanism between the turbine and the generators or else high-speed generators for direct connection; both methods are used. The *De Laval turbines* are very high-speed machines, and have special speed-reducing gears; the *Parsons turbines* and the *Curtis turbines* have lower rotative speeds, and dynamos have been designed to operate successfully direct-connected to either of these types. The three types mentioned are extensively used in the United States.

Some advantages of steam turbines are: reduced cost per kilowatt capacity of generating unit; reduced floor space required; reduced cost for labor and attendance; reduced losses from steam condensation, friction, etc.; and high efficiency at reduced loads. Economizers, condensers, etc. are also used with steam turbines.

16. Gas Engines.—A considerable number of electric-railway stations are operating in Europe with **gas engines**, as prime movers, and their use is being extended into the United States. A number of claims of superiority for gas engines are made, most of them with seemingly good ground. For small plants, gas engines with the necessary gas producers and other accessories are more expensive to install than steam plants, but the claim is made that gas engines will operate with so much greater efficiency that the excess in first cost is more than balanced by saving in the cost of operation. Where natural gas or waste gas from blast furnaces or coke ovens is available, there can be little question as to the superior economy of gas engines. Methods of speed control have been so far perfected that gas engines will drive alternators for successful parallel operation, which is all that can be required of any prime mover in the way of speed regulation. Experience of several years with plants in continuous operation has proved that repair charges are not excessive. Competent engineers are free to predict a greatly extended use of gas engines for power-station work.

ELECTRICAL EQUIPMENT

DIRECT-CURRENT DYNAMOS

17. In most urban railway systems, except the very large ones, the energy for operating the cars is supplied by direct-current dynamos. In suburban and interurban systems, alternating-current generators, or alternators, are more frequently used to supply the energy, which is then transformed and converted to the form required by the motors.

18. Dynamos for railway work are constructed according to the same general principles as are those for transmission and lighting. These dynamos must be exceptionally well built, so as to withstand the sudden stresses thrown on them, and they should be capable of handling excessive overloads for short periods without injury. The dynamos

are wound for the voltage at which the car motors are to operate, usually from 500 to 600 volts, and are connected directly to the line, the positive dynamo terminal to the trolley or its feeders and the negative terminal to the rails. The generators may be either direct-connected or belt-driven; the former type is now installed in most new stations, especially where the units are fairly large. Smaller units, if installed where floor space is not too restricted, are usually belt-driven.

19. The Westinghouse six-pole belt-driven street-railway generator shown in Fig. 2 has three bearings, one at each end

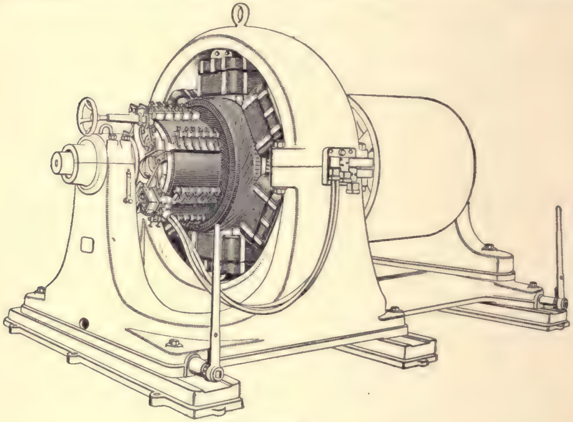


FIG. 2

of the shaft and one between the armature and the pulley, so that there is no hang-over effect. A belted generator is not so efficient commercially as a direct-connected generator of the same type and output, but for units up to 300 horsepower the difference is very slight. The amount of power lost in friction on a belted generator depends to a great extent on the method of setting up the machine. If there is not sufficient space between the dynamo pulley and the driving pulley, it will be necessary to run with a very tight belt, resulting

in high bearing losses and, in extreme cases, in hot boxes. The distance between centers of pulleys should be from 15 feet for narrow belts to 30 feet for wide, heavy belts, and the belt should run so that the loose side—usually the top—has an undulating motion, the tension being just sufficient to prevent slipping.

20. Armature.—In Fig. 3 (*a*) and (*b*) are shown two views of a typical **armature** for a direct-driven railway generator. The construction is very substantial, and the commutator *A* is of ample proportions. The conductors on the armature are in the shape of rectangular copper bars *a*, *a* bent into loops, or coils, the sides of which are sunk into slots in the periphery of the iron core. The ends of these coils are connected at the commutator end to the bars by the strips, or commutator leads, *b*, *b*. The laminated iron core on which the conductors are carried is mounted on the heavy spider *D*, which is keyed to the engine shaft.

21. Equalizer Rings.—Large multipolar armatures are nearly always *parallel*, or *multiple*, connected, thus making as many paths for the current to pass through the armature from positive to negative brushes as there are poles. In each path, an electromotive force is generated by the armature conductors passing under the poles. If the electromotive force is the same in all the paths, the current will divide equally among them; but if for any reason more lines of force are cut under some poles than under others, unequal electromotive forces will be generated in the various paths and unequal division of current will result. For example, if the air gap under a pole should become lessened, it will be easier for lines of force to cross the short air gap than the longer ones, and an increased number of them will travel through that path. Armature conductors passing under the short air gap will then generate a larger electromotive force than those at the same moment under long air gaps, and hence will carry more than their share of the armature current. The unbalancing may become so great that the electromotive force in one path will overpower that in another and

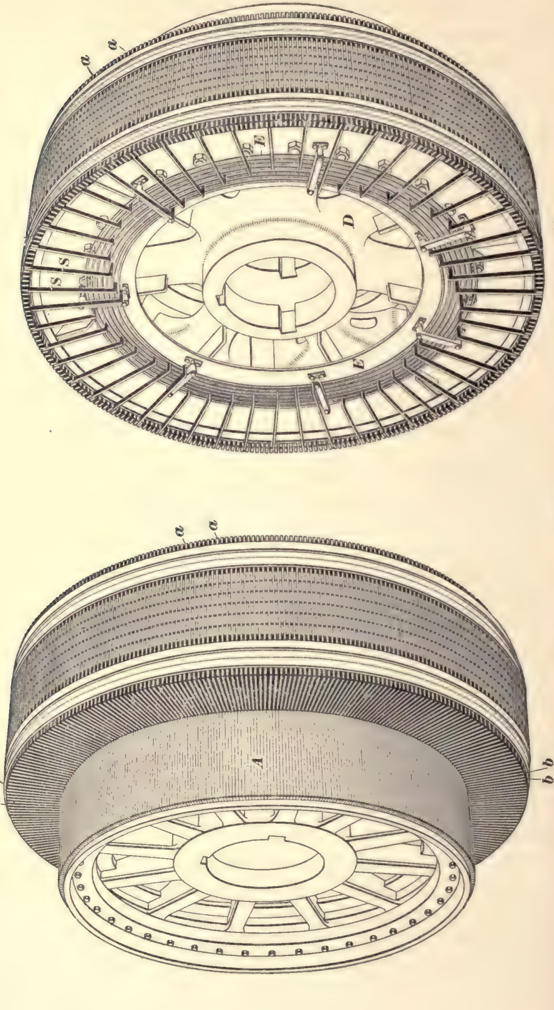


FIG. 3

reverse its current. Heavy local currents may be set up, resulting in excessive mechanical and electrical stresses accompanied by a violent trembling of the whole machine and by severe sparking and flashing. This phenomenon is known as **bucking**, and, to prevent it, armature conductors two poles apart, which should always remain at the same

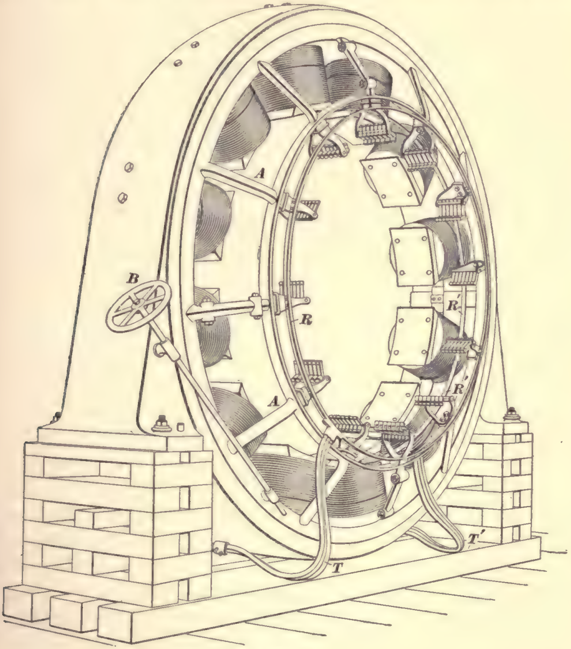


FIG. 4

potential, are cross-connected by **equalizer rings.** Seven equalizer rings are shown at E, E, Fig. 3 (b), and are connected to the armature conductors by leads S, S. Each ring has seven connections, indicating that the armature is for a machine with seven pair of poles. These rings are not

always necessary, especially on the smaller machines, but they are nearly always used on the larger sizes. They are never necessary except with parallel-wound armatures.

22. Field Magnet.—Fig. 4 shows a field frame, with field coils in place, for a typical 650-kilowatt direct-connected street-railway generator. The magnet yoke may be either of steel or of cast iron, and the poles may be bolted or cast-welded to it. The figure shows twelve poles bolted to the frame. The brush holders, of which there are as many sets as there are poles, are carried by the frame AA, which is fitted into the field casting so that it may be revolved through a small arc by turning the wheel B; this permits the brushes to be adjusted to the point on the commutator that gives the least amount of sparking. Alternate sets of brushes connect to the *bus-rings* R, R', and the main armature cables T, T' are attached to these rings. The line on the surface of each field coil marks the division between the shunt and the series winding.

23. Field Winding.—Practically all direct-current dynamos used for street-railway work are compound wound. In the early days of electric railroading, shunt dynamos were tried but proved unsatisfactory, principally because of extreme variation of voltage with varying load. Compound-wound dynamos may be adjusted not only to hold the voltage constant, but may, if desired, be wound to give an increasing electromotive force with increasing load. The electromotive force of a shunt dynamo, however, falls as the load increases. The standard practice, therefore, is to wind street-railway generators for 500 volts at no load and from 550 to 600 volts at full load; that is, they are *overcompounded* from 10 to 20 per cent. so as to compensate for the line drop. The voltage at a point to which current is flowing out on the line, possibly at the extreme end, will therefore be maintained constant. For example, if current were flowing to the end of the line, causing a line drop at full load of 50 volts, and the generator were overcompounded 10 per cent. or from 500 to 550 volts, the pressure at the end of the line would remain constant at 500 volts. When current is flowing in the lines, the pressure

cannot be maintained constant at more than one point; if it is constant at the farther end of the line, it will fluctuate at all other points as the load changes, and if constant at the station, it will fluctuate at all points on the line.

In spite of the fact that a railway system may be supplied by a good machine heavily overcompounded, it is quite common for the voltage on remote parts of the system to vary between wide limits; in some cases the car lamps almost go out every time a car is started or its speed increased. That such a state of affairs exists is in no way due to a fault in the dynamo. If the dynamo is compounded for a 10- or 20-per-cent. drop in the line, it cannot compensate for a 40- or 50-per-cent. drop due to a poor rail-return circuit, nor can it compensate for the drop to some point 4 or 5 miles farther out on the line than it was originally adjusted for. As a rule, compound-wound dynamos have a shunt in multiple with their series field. The amount of overcompounding depends on the relative resistance of the series-field winding and its shunt. By adjusting this relation, the overcompounding can be adjusted. Anything that changes the adjustment—for example, a loose connection—changes the overcompounding.

24. Connections for Compound-Wound Generator. In Fig. 5 is shown a sketch of the connections of a four-pole railway generator, in which A represents the commutator. The machine has four brush holders b, b, b', b', but only two armature terminals P and N, because alternate brush holders are connected together by the bus-rings, represented by dotted curves $b\,b$ and $b'\,b'$. If the machine has eight or ten poles and eight or ten brush holders, it would still have only two armature terminals, because all brushes of the same polarity would be joined together.

Each field coil is divided into two sections, a thin section O, representing the series field, lying next the field frame, and a thick section E, representing the shunt field, lying next the armature. The series field is usually made of copper strip, and the shunt field of fine wire. It makes no difference what their position is relative to each other;

for the series field is sometimes placed next the armature instead of as shown. The two field windings are usually placed side by side, so that either can be repaired without destroying the other; this is not always done, however, as the series-field coils of some good modern machines are wound of thin copper sheets, the full width of the winding spaces, lying next the pole core. The shunt field winding is then placed over the series.

The actual arrangement of the connections varies somewhat with different makes of machines. In the connections shown in Fig. 5, one end of the shunt field connects to block Q by means of a small connecting screw, and the other

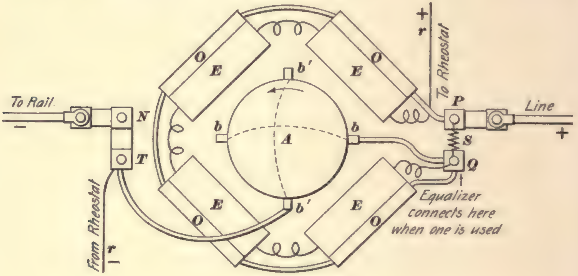


Fig. 5

end passes to the field rheostat and comes back to the negative side of the dynamo at block T. The cable on the right, marked *Line*, leads from the positive terminal P to the trolley wire; the line cable on the left comes from the rail to the negative terminal N. The current comes out of the armature by way of the b–Q armature terminal, and separates into three parts at the block Q. One part takes the path Q–E–E–E–E–$r+$, through the field rheostat, and returns by way of the rheostat wire $r-$ to the negative block T. Another part takes the short path from Q through the series-field shunt S to block P, while the third part reaches block P by way of the path Q–O–O–O–O–P, thus flowing through the series coils.

The shunt field of any compound-wound dynamo should be so connected that the machine will pick up and hold its voltage on an open circuit. For railway work, the series and shunt fields should be so connected that their effects are cumulative; that is, they must not oppose each other, as otherwise the effect of the series field will be to reduce the voltage instead of to increase it.

25. Series-Field Shunt.—The **series-field shunt** is usually made of German-silver ribbon. German silver is used because not only is its resistance high, but this resistance remains comparatively constant throughout wide variations in temperature. The strips are folded back and forth, well wrapped with heavy tape, painted with insulating paint, and provided with terminals on the ends. Fig. 6

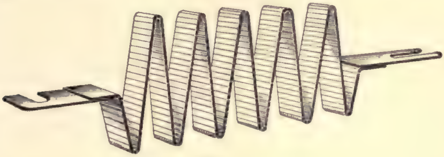


FIG. 6

shows one method of folding a series shunt. Other methods are used according to the shape of the machine and the taste of the designer. The shunt should always receive its final adjustment after the dynamo is heated. In fact, all the final adjustments are made when the machine has reached its maximum temperature, and the results then obtained determine the rating. The exact results marked on the name plate cannot always be obtained when a dynamo is first started, because all the windings are cold and their resistance is lower than when the final adjustments were made.

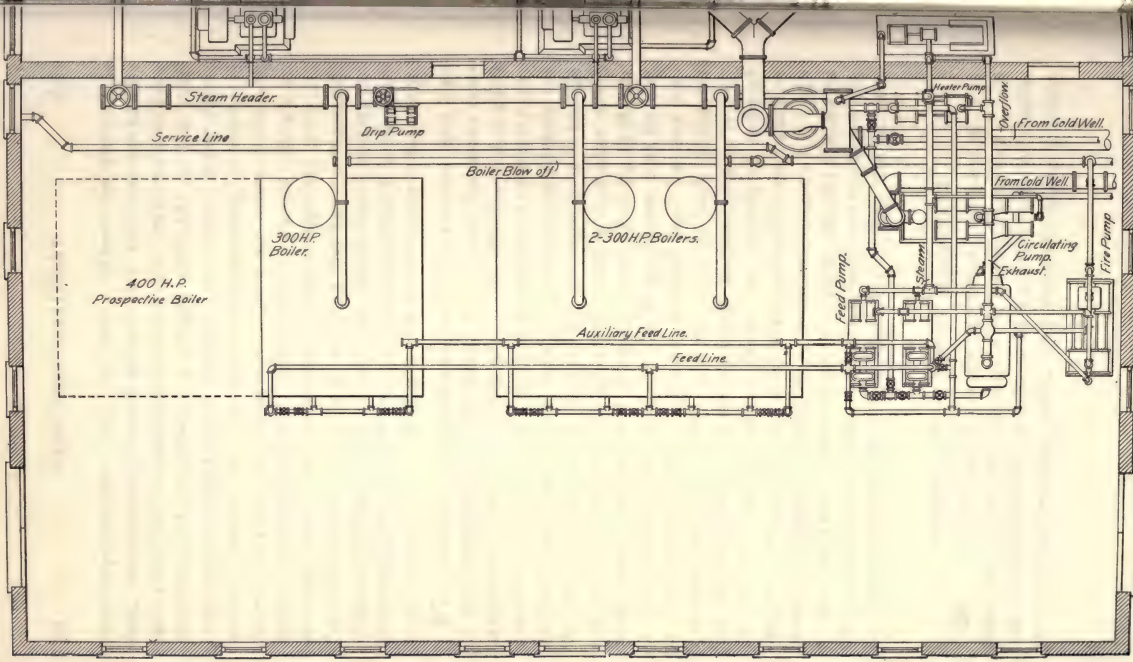
26. A dynamo tender should know the proper adjustment of the field rheostat in order to obtain normal voltage on open circuit after the dynamo has become heated. A dynamo adjusted for a given regulation when hot will overcompound too much when cold, but this condition does not

last long enough to do any harm. When the machine is cold, the attendant should not advance the rheostat handle bar at once to the position that will give the normal voltage when hot, but should work it around gradually to that position as the fields become heated. In a great many cases, the full benefit of a dynamo's compounding property is never made use of; especially is this so where there are several compound-wound dynamos to be run in multiple on the same load. The resistances of the series-field coils and the series shunts should be so adjusted that the machines will compound alike when hot, and then, when the rheostats are finally adjusted after the machines have reached full temperature, the load will divide properly without further adjustment.

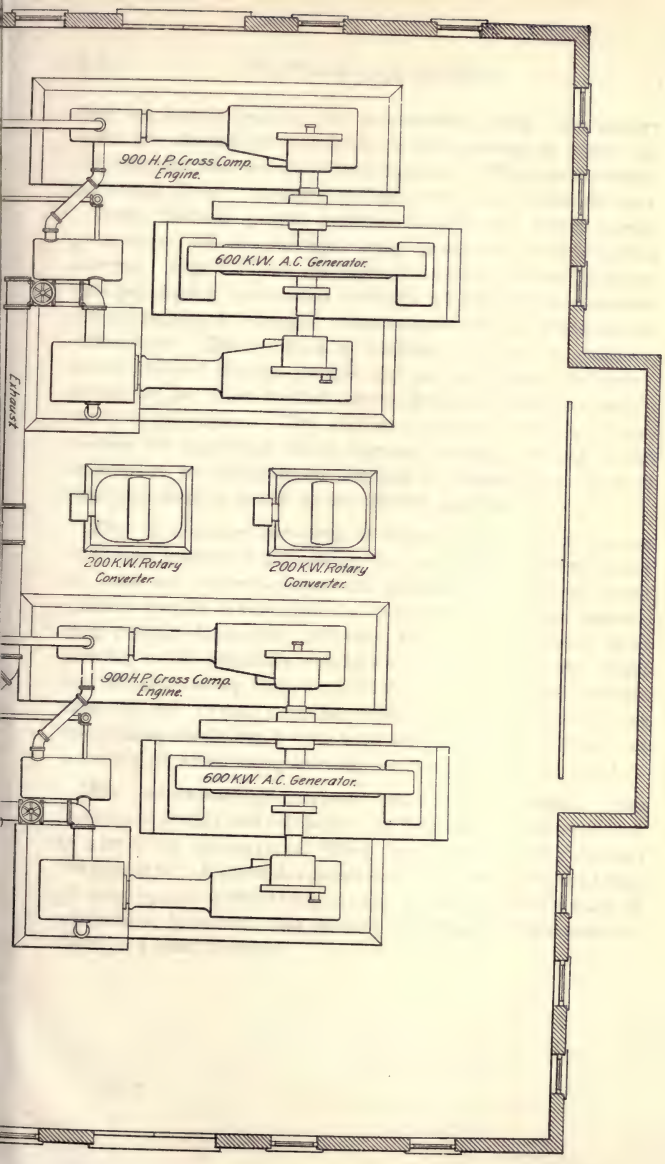
27. Capacity of Generators.—The number and size of the generators is determined from much the same considerations as for steam engines. The efficiency of a good generator, however, does not fall as rapidly at reduced loads as does that of an engine; hence, it is not so important for the generator to run at full load all the time as it is for the engine. A good modern generator does not change much in efficiency from one-half or three-fourths load up to 50 per cent. overload. The units should be so chosen that no one of them has to run on a greatly reduced load for any considerable length of time. For the sake of both generator and engine efficiency, there should be as few units as is consistent with the requirement given for periods of reduced output. It is an object also to have as few different sizes or types of machines as possible, in order not to carry too large a supply of repair parts in stock. There should always be units enough in the stations so that at least one can stand idle for repairs a part of the time without crippling the service.

ALTERNATING-CURRENT MACHINERY

28. Alternators for railway power stations do not differ from those for lighting or for transmission work. In fact, with the possible exceptions of the lately installed single-phase railway systems, and a very few multiphase systems



Steam Header.
Service Line
Drip Pump
Boiler Blow off
300 H.P. Boiler.
2-300 H.P. Boilers.
400 H.P. Prospective Boiler
Auxiliary Feed Line.
Feed Line.
Feed Pump.
Steam
Heater Pump
Overflow.
From Cold Well.
From Cold Well.
Circulating Pump.
Exhaust.
Fire Pump


900 H.P. Cross Comp. Engine.
600 K.W. A.C. Generator.
Exhaust
200 K.W. Rotary Converter.
200 K.W. Rotary Converter.
900 H.P. Cross Comp. Engine.
600 K.W. A.C. Generator.

that are hardly beyond the experimental stage, the energy from the alternators in railway power stations is used only for long-distance transmission purposes. The machines may be either direct-connected or belted to their prime movers.

Some railway power stations contain no direct-current generators, all the energy being generated as alternating current. Fig. 7 shows the plan of a traction plant in which the generating equipment consists of two 900-horsepower cross-compound engines direct-connected to 600-kilowatt alternators. The location of engines, alternators, exciters, steam boilers, piping, pumps, etc. are all plainly indicated. Attention is called to the special fire-pump installed solely for fire protection. The station contains two rotary converters for supplying direct current to local portions of the system; it was considered cheaper to supply local lines in this way than to install direct-current generators.

29. If a rotary converter is driven by an outside source of power, instead of furnishing its own motive power, it may be used as a **double-current generator**; that is, direct current may be taken from the commutator end and alternating current from the collector rings. The current then flowing in the armature conductors is the sum of the direct and the alternating currents, and this sum should not be more than the full capacity of the machine. Such machines are sometimes used when both a local supply of direct current and a supply of alternating current for transmission are needed.

30. Alternating-Current Railway Systems.—The discussion in this and the following Sections is with reference to plants for railways on which only direct-current motors are operated. Recent developments have brought some types of single-phase alternating-current motors to such a state of perfection, however, that special reference will be made to them in a later Section.

MEASURING AND CONTROLLING APPARATUS

SWITCHBOARD APPLIANCES

31. In order that the condition of the system may be known and controlled, there must be certain measuring and controlling devices. These may be called *switchboard appliances*, because they are usually grouped at one place in the station, that is, on the *switchboard*. Among them are also protective devices, which act automatically in case of any abnormal condition that may injure some part of the system.

INDICATING AND MEASURING INSTRUMENTS

32. The indicating and measuring instruments do not differ in principle from those already described for electric transmission and lighting. There should be an ammeter in circuit with each direct-current generator and one in each feeder circuit. There is also usually an ammeter to indicate the total output of all the generators. One voltmeter may be arranged so that it can be made to indicate the voltage of any one of several generators operating at approximately the same voltage. On account of rapidly fluctuating load and voltage on a railway circuit, the voltmeters and ammeters should be as nearly "dead-beat" as possible; that is, the hand should immediately respond to a change and should swing promptly to the new value without oscillating. **Weston instruments** are much used, because they are accurate, consume but little energy, and are dead-beat; their movement is caused by the reaction between the lines of force of a permanent magnet and a current of electricity, which is led through a movable coiled conductor in the magnetic field.

If the instrument is designed for measuring very small currents, it is usually capable of carrying all the current to be measured; but if designed to measure large currents, an ammeter shunt carries almost all the current, and the ammeter, being connected to the shunt terminals, receives only a very small current that is always proportional to the total current. The movable coil is attached to a core that carries the indicating hand. In order to decrease the current that flows through a voltmeter, the coil is wound with many turns of fine wire, making the resistance high; or, for higher voltages, an auxiliary resistance is used in series with the voltmeter coil. On high alternating voltages, potential transformers are used to step down the voltage for the voltmeter.

The **Westinghouse railway voltmeters** and **ammeters** have a movable iron vane to which the indicating hand is attached. The current to be measured, or a proportional part of it, is led through a coil that acts magnetically on the vane, causing it to move the hand.

33. The **Thomson astatic voltmeters** and **ammeters** contain two magnetic fields that are excited by a winding connected directly across the circuits on which the instruments are used. A movable coil carrying the current to be measured is mounted on an aluminum disk, so that the coil swings in one of the magnetic fields. To the shaft of the disk are also attached two small pieces of magnetic metal that swing in the second magnetic field, so that they tend to retard the motion of the disk. Any change in the voltage of the circuit changes both magnetic fields in the same ratio, so that, so far as they are concerned, the force tending to move the disk and the force tending to retard its motion always bear the same relation to each other. Any change in the current in the movable coil, however, destroys the balance and causes the disk to rotate through an arc proportional to the change in the current. In a voltmeter, the movable coil is also connected across the circuit; in an ammeter, the movable coil is connected in series with the

circuit and, if the current to be measured is very large, is shunted by a resistance that carries the larger portion of the current. The indicating hand is attached to the aluminum disk. Such instruments must have at least four terminals each; and if an incandescent lamp is used to illuminate the dial, six terminals are necessary.

Some railway stations are provided with **recording voltmeters** in which the hand traces a mark on a moving sheet of paper, thereby giving a complete chart of all fluctuations of voltage. The paper is usually in the form of a circular disk, which is slowly rotated, and the hand moves back and forth radially.

34. Synchronizers.—In stations in which alternating-current machines must be synchronized, some form of **synchronizer** is generally used. Fig. 8 shows a Lincoln synchronizer, which indicates at a glance whether the machine coming into action is running slow, fast, or just right. The instrument is constructed somewhat similar to a small two-pole motor; there is a laminated field excited by a fixed coil, which receives its energy through terminals *a*, *a* from the bus-bars or the machine already in operation. Between the field poles are two coils wound at right angles to each other on an armature core that is free to rotate. The armature coils receive their energy through terminals *b*, *b* from the incoming machine. The armature core carries the pointer *h*. When starting the machine to be synchronized, the hand revolves counter-clockwise, rapidly at first and then more and more slowly, until at exact synchronism it remains pointing directly upwards. If the speed of the incoming

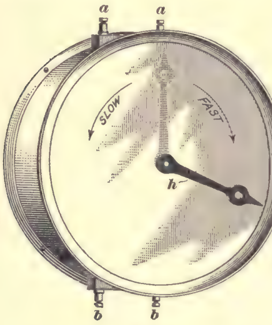


FIG. 8

machine becomes too high, the direction of rotation of the hand reverses and becomes clockwise. The incoming machine should be switched on to the circuit as the hand slowly approaches or remains standing at the vertical position.

35. Measurement of Electrical Energy.—The product of the direct-current volts and amperes gives the rate in watts at which work is being done at any instant. The watts multiplied by the time in hours gives the watt-hours of work done in a given time. The usual way of expressing the electrical output of railway power stations is in kilowatt-hours, which equal the watt-hours divided by 1,000. Sometimes, reference is made to horsepower-hours, which equal watt-hours divided by 746, there being 746 watts in 1 horsepower. In order to determine by means of a voltmeter and an ammeter the amount of energy in watt-hours delivered by a railway power station in a given time it would be necessary to read the volts and amperes at very frequent intervals, find the average of each, and multiply together average volts, average amperes, and time in hours.

36. Recording Wattmeters.—In Fig. 9 is shown a **Thomson recording wattmeter** for railway switchboards. This instrument automatically multiplies together three factors—volts, amperes, and time, in hours—and records the product in watt-hours or kilowatt-hours. The series coils of the ordinary meter are here replaced by the heavy copper bar *a*, through which the whole current output of the circuit in which the meter is connected passes, connection being made on the back of the board to the lugs *b*, *b*. Above and below this bar are the two small armatures *c*, *c*, which are connected in series with a resistance across the line, so that the current in them is proportional to the voltage. Current is led into the armatures through a small silver commutator *d*, as in the ordinary recording meter, and the reading in kilowatt-hours is registered on a dial *e* in the usual way. The damping magnets used to control the speed are contained in the case *f*. The main current flowing through the crosspiece *a* sets up a field surrounding it, and

this field acts on the two armatures *c, c*. The main current is so large that a sufficiently strong magnetic field is produced by passing the current through what is practically a portion of one turn only, whereas in small meters for electric-light circuits, several turns are required.

This wattmeter is constructed so that outside magnetic fields have little or no influence on it; for the armatures *c, c* are so connected that an outside field tends to turn them in

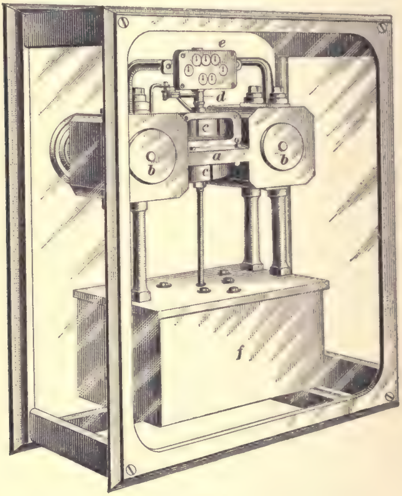


FIG. 9

opposite directions, and the disturbing effect is thus neutralized. The field set up by the instrument itself is in opposite directions on the upper and lower sides of *a*, so that these two fields propel the armatures in the same direction.

A recording wattmeter is sometimes installed on each car, so as to record the amount of energy required to run the car motors. Such instruments are especially constructed to withstand the severe shocks they must receive.

CONTROLLING APPARATUS

37. Switches.—For most railway work, **single-pole switches** are used. Fig. 10 shows a form of single-throw quick-break switch much used for direct-current railway circuits carrying not over 3,600 amperes. Although the switch is single pole, each blade is made double, so as to increase both the radiating surface and the contact surface at the clips. The double blade *a*, carrying the handle, is connected to a double blade *b* by coiled springs *c*, *c*. Both blades *a* and *b* are pivoted at *d*, so that when the upper blade *a* is withdrawn

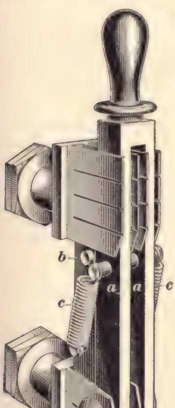


Fig. 10

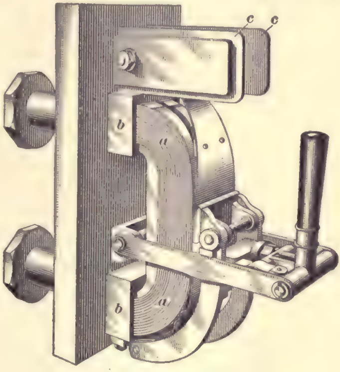


Fig. 11

from the clips the springs are stretched until the tension becomes sufficient to cause blade *b* to fly out, thus quickly breaking the arc. Such switches are also made double-pole or double-throw, if required, the double-throw type having another double blade similar to *b* attached to the top of the main blade *a*.

Fig. 11 shows a switch, with laminated contacts *a*, *a*, for circuits carrying as high as 4,000 amperes normal load. The final break, which occurs after the main contacts have

left the contact blocks *b*, *b*, is made by a secondary contact strip passing between blades *c*, *c*, which are the poles of a magnet. Whatever arc is made is thus magnetically blown out.

38. For breaking circuits of higher potential than that ordinarily used for direct-current railway systems, specially designed switches are employed. Those using a modification of the quick-break principle illustrated in Fig. 10 are employed for breaking moderate currents at as high as 5,000 or 6,000 volts pressure. Other switches are so arranged that a long arm is thrown back so far and so quickly that a potential as high as 20,000 volts is broken without a destructive arc.

39. Stanley Slide Switch and Circuit-Breaker. Fig. 12 shows a three-pole **Stanley slide switch**, which is

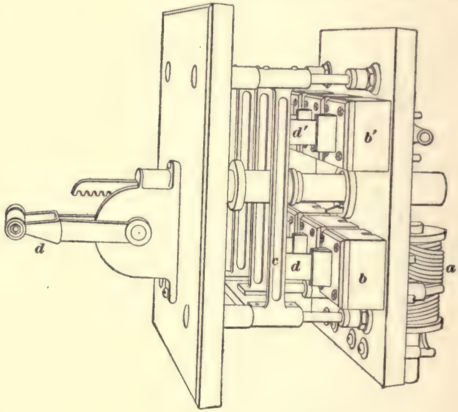


FIG. 12

provided with an automatic attachment that will open the switch whenever the current exceeds the amount for which the circuit-breaking device is adjusted. The attachment consists of a solenoid *a* through which the main current flows. When the current exceeds the allowable amount, the

solenoid releases a catch and a spring throws the switch out. If it is desired not to use the switch as a circuit-breaker, the automatic device can be cut out. The switch terminals are mounted in the insulating blocks *b*, *b′*, of which there are two for each pole, making six terminals. For each pole there is also a crosspiece *c* provided with blades *d*, *d′*, which are forced into contact by swinging the switch handle upwards. The motion of the handle is transmitted to the crosspieces by means of a rack and pinion. When the switch is opened, the blades are withdrawn from the clips, and as soon as they leave the insulating pieces, a shutter arrangement closes the opening, thus destroying the arc. Switches of this type are made in a number of sizes and are capable of handling as high as 60 amperes at 3,300 volts.

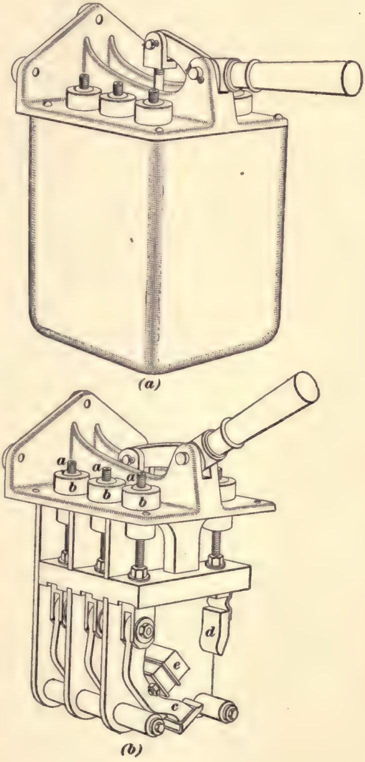


Fig. 13

40. Oil Switches. While the high-pressure switches already described are still much used, the present standard practice in high-tension work is to use switches that break the arc under

oil. Many types of **oil switches** are in use; Fig. 13 (*a*) and (*b*) shows a three-pole switch made by the General Electric Company, which is recommended for breaking a circuit on which the pressure is not over 3,500 volts and the current not over 300 to 350 amperes. In (*a*) is shown the switch enclosed ready for mounting on the front of the switchboard; this same style of switch is also made for mounting on the back of the board, with the handle extending through to the front. In (*b*) is shown the switch with the oil tank removed. The terminals *a*, *a*, *a* are mounted in porcelain insulators *b*, *b*, *b*. The contacts *c* are hinged and are mechanically connected together by a wooden crosspiece *e*, which is connected to the operating handle. The contacts *c* and *d* make a firm wiping contact with each other when the switch is closed.

41. Oil switches are made in many sizes up to those used for large, high-voltage transmission stations. Large switches are usually operated by small motors, by compressed air, or by electromagnets. Fig. 14 (*a*) and (*b*) shows a front and a side view, respectively, of a three-pole motor-operated oil switch having a separate chamber for the two contacts of each pole. The casing is made of brick and is provided with a removable iron door. These switches are designed with a view to using the smallest possible quantity of oil, since large quantities of oil increase the fire risk. In each compartment is a pair of brass cylinders *a*, *a* lined with insulating material, each cylinder having a contact sleeve at the bottom. The cylinders are filled with oil, and provided with porcelain insulating sleeves *b* at the top, through which slide copper rods *c*. The two rods in each chamber are connected together by the crosspiece *d*, so that when the rods are pushed down into the contact sleeves, the two cylinders are electrically connected, the current passing from one cylinder to the other by way of rods *c*, *c* and crosspiece *d*. The crosspieces *d* are attached to a crosshead *e* by means of wooden rods *f*, and the motion of the crosshead is controlled by means of the motor *g*, which is started from the switchboard.

Whenever the solenoid *k* is excited from the switchboard, the motor is thrown into gear with a worm that operates a worm-wheel in the casing *h*. On the worm-gear shaft is a crank *l*, that, together with a link *m*, forms a togglejoint. When the switch is out, as shown in the figure, spring *n* is compressed and the switch tends to close, but is prevented

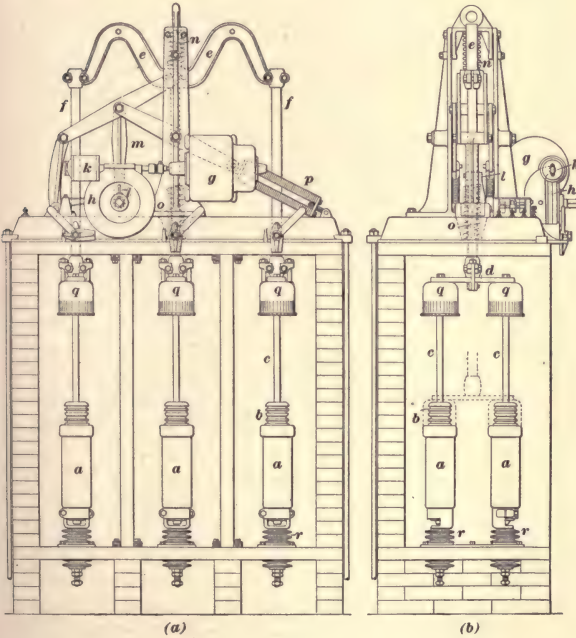


FIG. 14

from doing so because the toggle *lm* is on center. The crank *l* is driven from the worm-gear by means of a ratchet, so that as soon as the toggle is moved off center by the motor, the crank is carried around by the force of the spring on the crosshead through nearly a half revolution independently

of the movement of the motor. As soon as the crank stops, the ratchet at once takes hold and the crank is turned through the remainder of the half revolution until the toggle is again on center. The switch is now completely closed, and the motor is stopped automatically by means of a rotating switch moved by the worm-gear shaft. When the switch is closed, spring *o* is compressed and springs *p* are stretched. The switch is opened by again starting the motor from the switchboard, thus throwing the toggle off center and allowing the springs to throw up the crosshead. In the opening operation, the springs *p* assist spring *o*, so that the opening is quicker than the closing, the time required being about 1 second.

For switches that have to handle large currents, the rods *c*, *c* are provided with auxiliary bell-shaped contacts *q*, *q*, which, when moved down to the dotted position, as shown in (*b*), make contact with the upper part of the cylinders, thus relieving the rods of the current. When the switch moves up, these contacts leave the cylinder before the contact is broken inside the cylinder, so that no arcing takes place at the auxiliary contacts.

The cylinders are mounted on ribbed porcelain insulators *r*, *r*, and are arranged so that they can be easily removed from these supports. The switch shown in Fig. 14 has a range of movement of 17 inches and is capable of handling 300 to 800 amperes at 12,000 volts.

42. Field-Discharge Switch.—In addition to the main switches, there are on the generator panels of most railway switchboards a smaller station-lighting switch, a voltmeter switch for connecting the voltmeter to the generator, and a field-discharge switch. If the shunt-field circuit of a large railway generator is suddenly broken, the inductive discharge may puncture the insulation; to prevent this, a **field-discharge switch** is installed, with connections as shown in Fig. 15. The switch *s* has two contact segments $a\,a'$, which are separated by a gap narrow enough to be bridged by the tongue *t*. The tongue is shown in its normal running position; when it is turned to the position indicated by the

dotted line, the field is short-circuited through a resistance r' and a pilot lamp l, so that the field circuit is not broken. When the tongue bridges the gap between a and a', the resistance and the pilot lamp are connected in parallel with the shunt field directly across the terminals of the generator. By means of the pilot lamp the attendant in starting up can tell at a glance whether the generator is building up properly or not. The field-discharge resistance is sometimes incorporated in the field rheostat, so that, simultaneously with the opening of the circuit through the field-regulating rheostat, the discharge resistance is inserted in series with the field.

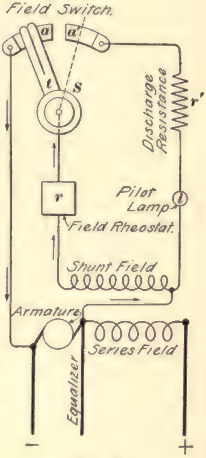


FIG. 15

43. Fuses and Circuit-Breakers. Fuses and circuit-breakers may be classed under the same general head as switches; namely, *circuit openers*. But while switches are arranged to open the circuit only at the will of the station attendants, circuit-breakers are designed to open it automatically in case of overloads that are likely to work injury to any part of the apparatus.

A **fuse** is any piece of wire or metal strip so proportioned that it will melt, or *blow*, and thus open the circuit before any part between the fuse and the generator, or source of electromotive force, has been injured. The fuse may either be open to the atmosphere or enclosed in an insulating fireproof cover.

A **circuit-breaker** is an automatic switch designed to open a circuit when the current exceeds a predetermined amount; it is not ordinarily used as a switch, but as an automatic safety device. Circuit-breakers are made in many varieties and for use with either direct or alternating current. As these devices are intended to open a circuit only when excessive current is flowing, there is a provision for

breaking the arc before it can injure the contacts. The arc may be suppressed by opening the circuit with a quick, positive action within a magnetic field, thus forming the arc and and blowing it out so quickly that it can do little injury; or, the final break may be made to occur between carbon contacts, which are easily replaced when burned.

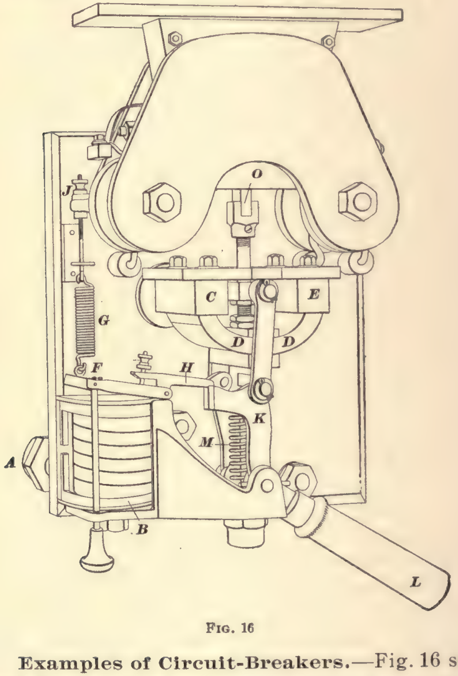


FIG. 16

44. Examples of Circuit-Breakers.—Fig. 16 shows a **General Electric type M circuit-breaker** recommended for use on railway circuits of 500 to 600 volts direct current. The main current enters by way of the stud A, traverses the heavy coil B, and passes to a connection on the back of the heavy copper contact-block C. When the breaker is

closed ready for service, as shown in the figure, the current passes from *C* through the laminated contacts *D*, *D* to the block *E*, and thence out to the line through a heavy terminal on the back of the board. In this position, the hinged iron armature *F* is held up by a spring *G*, the tension of which depends on the adjustment of a thumbscrew *J*. Attached to plate *F* is a trigger *H*, which has on the under side of its end a shoulder against which a projection on the main handle yoke *K* bears.

To set the breaker, the main handle *L* is pulled down hard; this forces *D*, *D* up against blocks *C* and *E*, and also

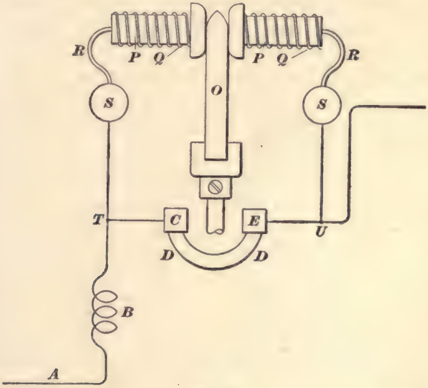


FIG. 17

causes the projection on *K* to engage trigger *H*, which holds the circuit-breaking parts in place. In setting the switch, spring *M* is extended, and if the current exceeds the value for which the breaker is set to operate, the armature *F* is drawn down by the solenoid *B*, the trigger *H* releases the arm *K* and contacts *D*, *D* are drawn down quickly by action of the spring *M*. This opens the main circuit, and if there were nothing to prevent, very bad arcs would form from *C* to *D* and from *D* to *E*, and these contacts would soon become so much roughened by burning as to be useless.

To prevent this injury, a shunt circuit *T–S–R–P–O–P–R–S–U*, Fig. 17, is provided, in which are two blow-out coils *S, S*. When the breaker is closed, the tongue *O* is pushed up between the contacts *P, P*, which are held firmly against it by the action of the springs *Q, Q*. When the breaker is tripped, the main circuit opens at *C–D* and *D–E* a little before the tongue *O* is withdrawn from between *P, P*, and the main current, instead of arcing across the main contacts, momentarily flows through the shunt circuit, thus strongly magnetizing the coils *S S*. A gap in the magnetic circuit of these coils is so arranged that the arc formed at the final break between *O* and *P, P* is quickly forced away to one side, or *blown out*, by the magnetism. The auxiliary contacts are easily replaced when they become burned; they should be kept clean and free from smoke and dust.

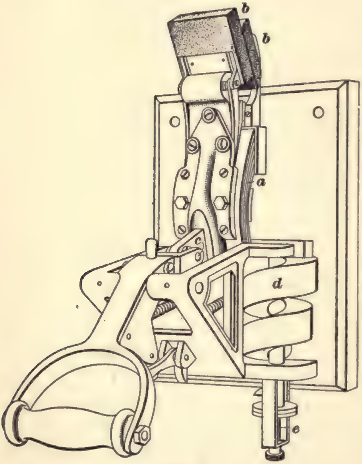


Fig. 18

This type of circuit-breaker is made in sizes for 150 to 10,000 amperes. The tripping current on each size may be adjusted for any desired value up to 50 per cent. above the rated capacity of the breaker. A low-voltage release coil, which will cause the breaker to open when the voltage falls below a certain value, may be applied if desired.

45. In Fig. 18 is shown the **Cutter (I. T. E.) laminated-type circuit-breaker.** The main contact *a* is laminated and is pressed against the contact surfaces by means of the handle working through a togglejoint

at *c*. When the current exceeds the amount for which the breaker is set, the core inside the tripping coil *d* is suddenly drawn up against a trigger, allowing the breaker to fly out. The position of the core in the tripping coil can be changed by adjusting screw *e*, thereby varying the current at which the breaker trips. Auxiliary carbon contacts *b*, *b* do not open until after the main contact, so that the burning action is confined to the carbon contact surfaces.

The **Westinghouse type C circuit-breakers** are very similar in general appearance and operation to the type shown in Fig. 18, the main difference being in the arrangement of the tripping coil. They may be used on either direct- or alternating-current circuits.

46. Field Rheostats.—**Field rheostats, or resistance boxes,** are used in connection with all railway generators, and are connected in series with the shunt-field winding, so that the field current, and hence the voltage of the generator, may be adjusted. The field resistance is not intended to be used for regulating the voltage to suit the variations in load; it is used to adjust the voltage when the machine is first started, and some of it must be cut out as the field coils warm up.

Field rheostats used on railway boards are made in a great variety of designs, but in all cases they consist of a resistance split up into a large number of sections that are connected to a multipoint switch, so that any amount of resistance may be cut in or out. In some styles, the resistance is made up of German-silver or tinned-iron wire coiled into spirals and mounted in a well-ventilated iron box. In others, the wire is formed into zigzag shape and mounted in enamel on the back of cast-iron plates. In still others, the resistance is in the form of cast-iron grids of zigzag form; this style makes a substantial resistance that is well ventilated and is especially suited to rheostats of large capacity. In all cases, rheostats should be constructed so that they will be perfectly fireproof and at the same time allow easy radiation of the heat generated in them so that the resistance will not be burned.

47. Fig. 19 shows a **General Electric field rheostat** of a type much used for 500-volt railway switchboards. The rheostat is mounted on the back of the board and is operated by the hand wheel *W* in front. The resistance wire or strip is wound on asbestos tubes that are afterwards flattened and clamped between pieces of sheet iron covered with asbestos, the iron strips serving to conduct the heat from the wire.

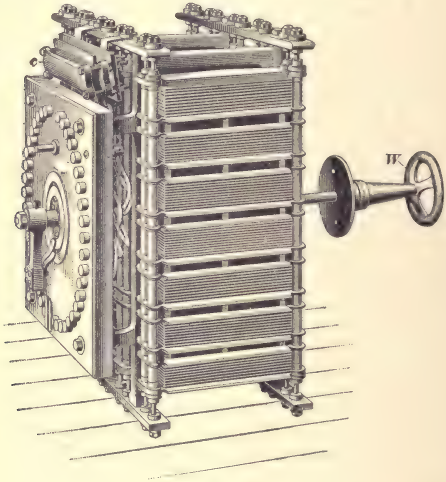


FIG. 19

The connections are shown in Fig. 20. A small auxiliary resistance *c* is connected through the contact rings *b*, *b* to contacts *a*, *a*′. When the arm is in a position where *a*, *a*′ are on adjacent contact points, resistance *c*, which is equal in amount to the resistance between the rheostat contacts, is in parallel with the resistance between the contacts. Thus, by using resistance *c*, the change in resistance due to a movement of the arm from contact to contact is one-half what it would be if no auxiliary resistance were used. The variations in field strengths are therefore as gradual as in an ordinary rheostat

using twice the number of contacts. When a rheostat is too large to mount on the back of the board, it may be set on the floor or on a pedestal and operated by means of a chain and sprocket wheel.

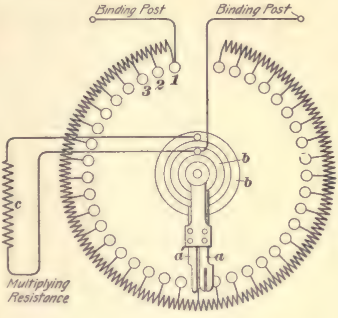


FIG. 20

LIGHTNING ARRESTERS

48. A lightning discharge in passing from a trolley line across the gap of an arrester forms an arc that connects the positive side of the generator with the earth. As the negative generator terminal is permanently connected to the earth, a circuit of comparatively low resistance between the machine terminals is completed by the arc, and if it were not soon suppressed, damage to both the machine and arrester would result. In order to decrease the generator current that would follow a discharge across the gap, a non-inductive resistance is inserted in the path from the arrester to the ground. This resistance does not interfere seriously with the escape of the lightning discharge. Means are also provided for suppressing, or breaking, the arc by blowing it out magnetically, by distending it, or by smothering it in a confined space.

49. The principal objection to air-gap arresters is that the potential, before it becomes high enough to jump across the gap, may endanger some other parts of the system. If such arresters are used, each trolley or feeder line leaving the station should have one; it is not necessary to use an arrester in the grounded return line. The arresters may be installed on the switchboard or near the point where the lines leave the building. The station arresters, however, should not be the sole dependence for the escape of high-potential charges on the lines; arresters should be liberally distributed along the lines.

50. Fig. 21 shows the principle of the **Westinghouse tank arrester,** a type that has been much used on grounded

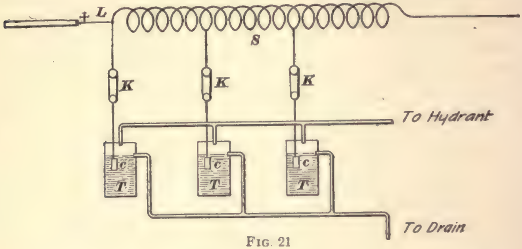


FIG. 21

street-railway circuits. The arrester is connected to the series of choke coils S by closing plug switches K, and consists of tanks T, containing carbon electrodes c. The line is attached at L, and the other end of the choke coil goes to the dynamo or line bus-bar. A circulation of running water is maintained through the tanks, and there is thus a continuous non-inductive path of high resistance by way of the drain pipes to the ground for any charges that may accumulate on the line. The water has such a high resistance that the leakage of dynamo current to ground is not large. There is some leakage, however, and therefore this type of arrester is connected to the system only during thunder storms; while connected it affords very efficient protection.

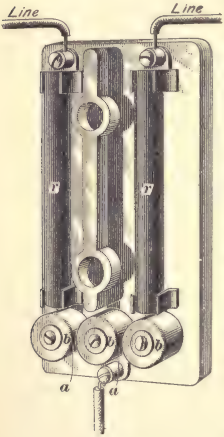


FIG. 22

51. Arresters for high-potential alternating-current lines are based on the principles already explained for air-gap arresters. The higher the potential of the circuit to be protected, the greater must be the air gap to prevent

the normal line voltage from arcing across. Instead of using one large air gap, however, a number of smaller ones are used in series and a non-inductive resistance is generally used in series with these.

Fig. 22 shows an arrester made by the General Electric Company for alternating-current circuits. A non-inductive resistance *r* is inserted in the circuit in order to limit the current following the discharge. The spark gaps *a*, *a* are between

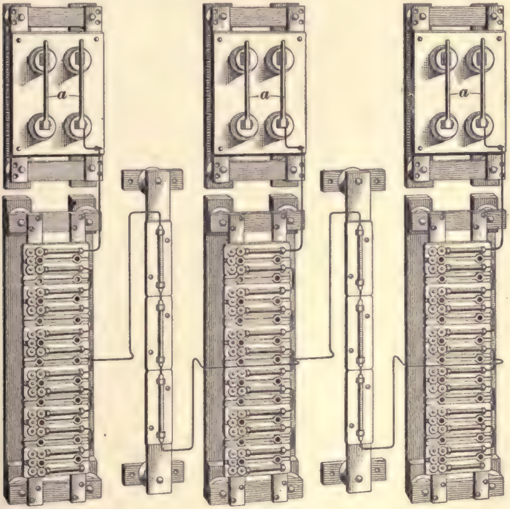


FIG. 23

the heavy metal cylinders *b*, *b*, *b*, the middle one of which is connected to ground. The arrester shown is a double-pole type intended for 2,000 volts alternating current; it is not suitable for direct current. By connecting a number of such arresters in combination, they may be used on very high voltages. Fig. 23 shows a 13,200-volt three-phase multiplex arrester made up of units such as shown in Fig. 22. The arrester shown in Fig. 23 is equipped with double-blade disconnecting switches *a*, *a*, *a*.

SWITCHBOARDS AND SWITCHBOARD CONNECTIONS

52. Modern **switchboards** in electric-railway stations are nearly always made of marble or slate, and are located and constructed along practically the same lines as boards for lighting and transmission stations. The tendency is to spare nothing in the effort to have the switchboard well constructed and convenient in every way, and many boards are models in this respect. If properly arranged, the switchboard is a great time and labor saver; it enables each dynamo and each circuit to be used as a separate unit; where occasion demands such practice, several circuits may be connected to one dynamo, or any or all of the dynamos may be cut out of circuit. All of these combinations may be effected, if necessary, without going near the dynamos.

To the switchboard should come connections from all circuits entering or leaving the station. On a board of considerable size, the connections become somewhat complicated; if carelessly or indifferently made, or if made in any but a permanent and substantial manner, they may become the cause of very serious trouble. If properly made, however, the connections permit complete and perfect control of most of the apparatus in the station. In some cases, even the engines are controlled from the switchboard.

53. Location of the Switchboard.—If the station is large enough to employ one or more attendants whose sole duty is to watch the switchboard, to see that each machine is performing its share of the work and that no machine is overloaded, the board may be located without special reference to the rest of the plant; but even then it is better to place the board so that all the station apparatus to be controlled can be observed by the switchboard attendants. If the station is small and one person must watch engines, dynamos, and switchboard, the board must be so placed that there is safe, easy, and quick access to all apparatus. The safety of the attendants should be the first consideration, and the safety and economy of the apparatus the second.

The less the distance between the dynamos and the switchboard, the less will be the loss in cable leads, and with the large current usually handled in a railway station this consideration may become very important. The board should always stand far enough from a wall so that there is ready

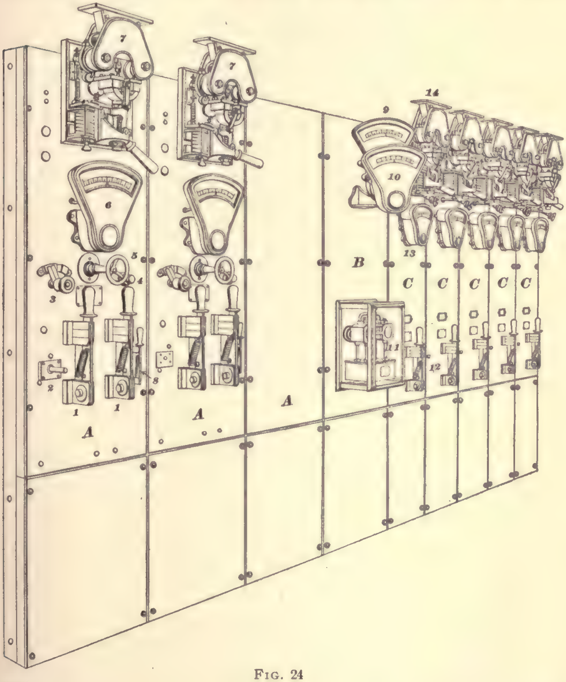


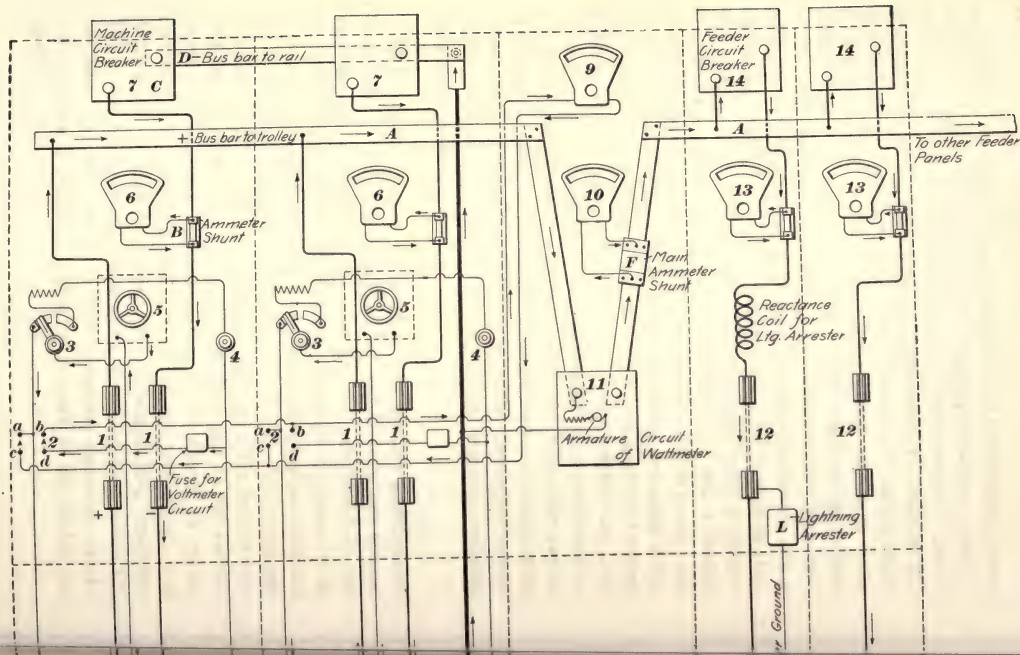
FIG. 24

access to all the connections on the back. Provision should also be made for an abundance of light and air.

54. Direct-Current Switchboards.—Fig. 24 shows a switchboard for a direct-current railway system. There are three generator panels *A*, *A*, *A*—one being blank for a future

installation—one total output panel *B*, and five feeder panels *C*, *C*, etc. Each generator panel is equipped with + and − main switches *1*, *1*, voltmeter plug *2*, field switch *3*, pilot-lamp receptacle *4*, field rheostat (operated by handle *5*), machine ammeter *6*, machine circuit-breaker *7*, and station lighting switch *8*. The total-output panel carries a voltmeter *9* that can be connected to either machine by means of the voltmeter plug, a total-output ammeter *10* that indicates the combined current output of the generators, and a recording wattmeter *11* that records the total output in kilowatt-hours. Each feeder panel is equipped with a single-pole feeder switch *12*, a feeder ammeter *13*, and a feeder circuit-breaker *14*. All instruments and circuits are connected to heavy copper bars, called *bus-bars*, arranged along the back of the board. Since the current on a ground-return railway system returns through the rails, which are connected to the negative bus-bar, the feeders are connected to the positive bus-bar only; hence, but one single-pole switch is needed on each feeder panel. In addition to the apparatus shown, each generator panel, and in some cases each feeder panel also, is equipped with a lightning arrester mounted behind the board.

55. Fig. 25 shows the connections for the switchboard illustrated in Fig. 24. Two feeder panels only are shown, and the instruments and the switches are numbered to correspond with Fig. 24. If lightning-arrester reactance coils are used on the switchboard, they will be inserted as indicated on the left-hand feeder panel at *L*, Fig. 25. The equalizer switches *E*, *E* are mounted on pedestals near the generators, and the equalizer connections are not brought to the switchboard. When the voltmeter plug is inserted in either receptacle, terminals *a* and *c*, *b* and *d* are connected, thus placing the voltmeter across the corresponding machine. The voltmeter connections are made at the machine terminals, or "back" of the switch, so that voltmeter readings can be taken before a machine is thrown in parallel by closing the switch.


Machine Circuit Breaker
7 C
D–Bus bar to rail
7
9
Feeder Circuit Breaker
14
14
+ Bus bar to trolley
A
A
To other Feeder Panels
6
6
10
13
13
B
Ammeter Shunt
F
Main Ammeter Shunt
5
5
3
3
4
4
Reactance Coil for Ltg. Arrester
11
Armature Circuit of Wattmeter
a
b
2
c
d
1
1
1
1
12
12
Fuse for Voltmeter Circuit
+
–
L
Lightning Arrester
Ground

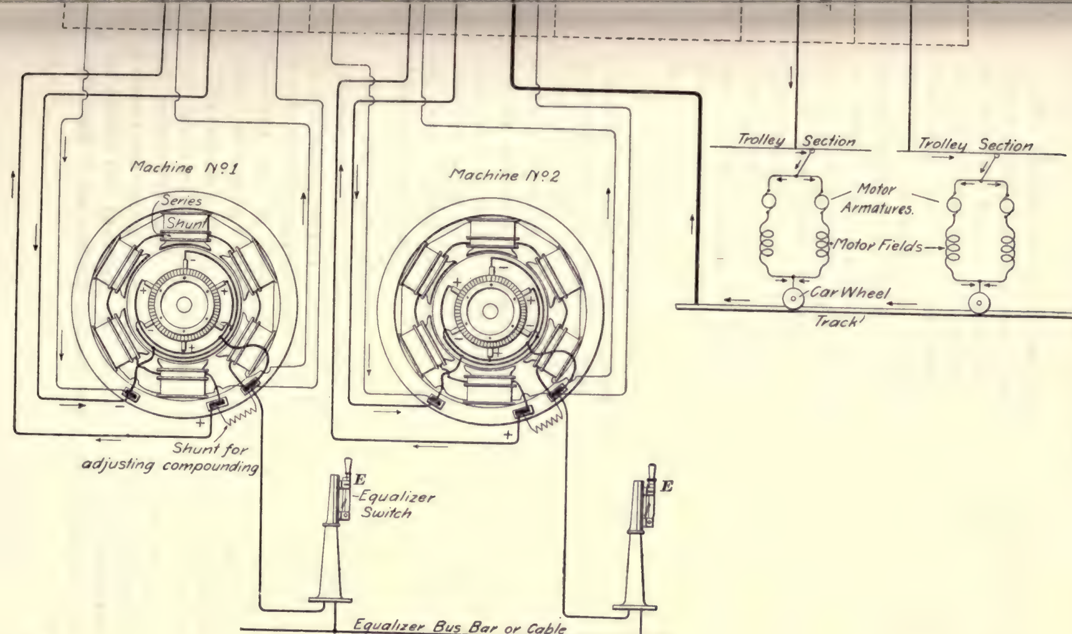

Machine No.1
Series
Shunt
Shunt for
adjusting compounding
Machine No.2
E
-Equalizer
Switch
E
Equalizer Bus Bar or Cable
Trolley Section
Trolley Section
Motor
Armatures.
Motor Fields
Car Wheel
Track

FIG. 25

56. The advantages of the panel type of construction are that it groups the apparatus belonging to each individual part of the plant by itself, and that it allows the board to be extended easily in case the plant is enlarged either by adding more feeders or more generating apparatus. Some boards have two voltmeters, one of which is permanently connected across the bus-bars and the other arranged so that it may be connected to any machine. This arrangement is convenient for connecting a machine in multiple at the bus-bars, but it is not essential that the board should be equipped in this way. The voltmeter is often mounted on a swinging bracket, as in Fig. 24, so that it may be readily seen by the operator. In case a total-output panel is not provided, the voltmeter is often mounted on a swinging arm at one end of the board, as in Fig. 26.

57. Alternating-Current Switchboards.—In many respects, the arrangement of ordinary **alternating-current switchboards** is similar to that of direct-current boards. They are usually built up in panels in the same way as the boards previously described. Owing to the fact that alternators are generally separately excited, the switchboard has some extra apparatus connected with the exciter that is not found on direct-current boards. The wiring and connections will also depend on whether single-phase or polyphase alternators are used.

58. In Fig. 26 is shown the front of a General Electric switchboard having three panels. The left-hand panel is for a direct-current exciter, the middle one for a three-phase alternating-current generator, and the one at the right for an outgoing line. A board can be made up of any number of panels, according to the number of machines or lines in use.

The swinging bracket at the left of the exciter panel carries one dial synchronizer *1*, two synchronizing lamps *2*, *2*, and one astatic voltmeter *3* for the exciter. The exciter panel contains one astatic ammeter *4*; a hand wheel for operating the exciter field rheostat; one two-point potential receptacle with plug *5*, for making connections to the voltmeter; one

single-pole single-throw positive switch *6*, with a fuse mounted on the back of the panel; and two single-pole single-throw switches *7* and *8*, one for the station lights and the other for circuits from which small motors for oil switches,

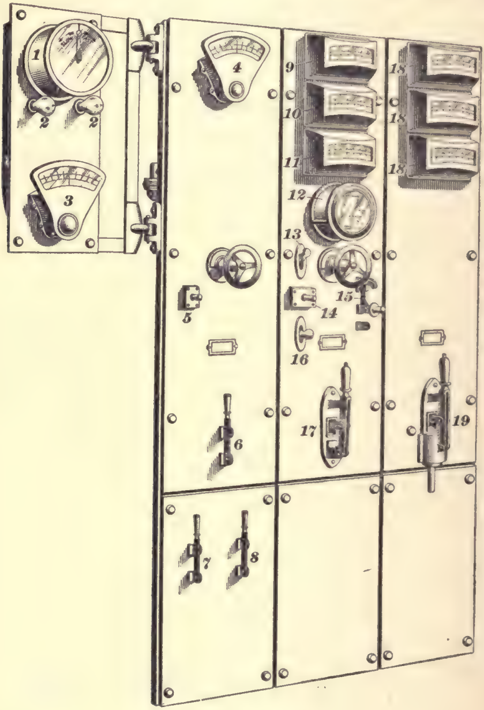


Fig. 26

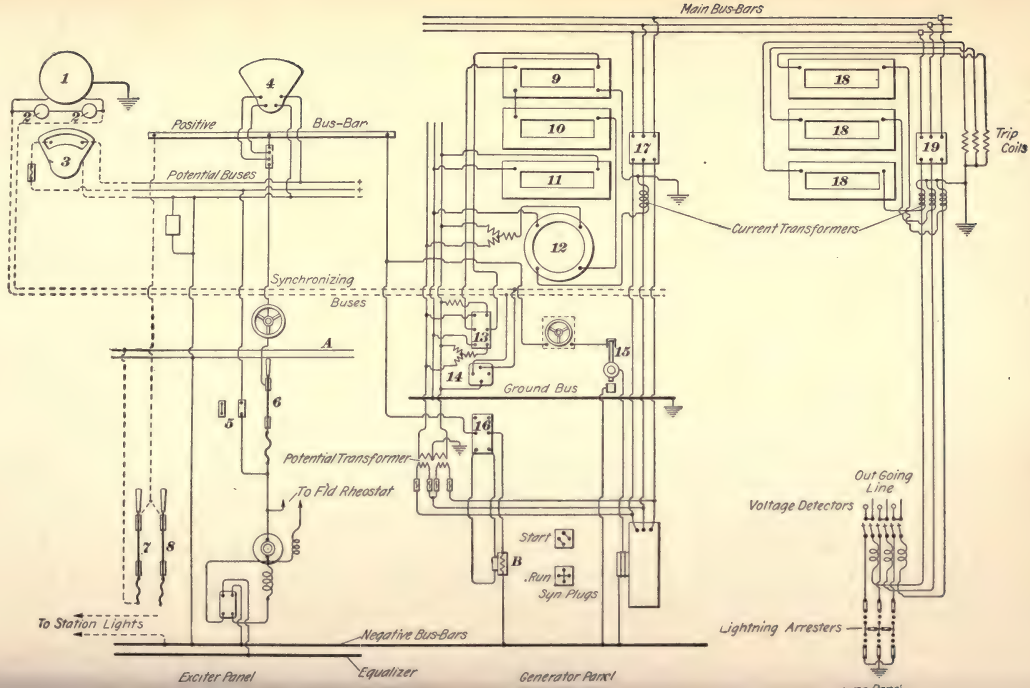
engine governors, etc. are operated. The two switches last named are necessary only on one exciter panel in a switchboard. In addition to the foregoing, there should be mounted on the frame of each exciter, or on a pedestal near it, one

single-pole single-throw switch for the negative lead and one for the equalizer lead. The panel is arranged to carry only a positive bus-bar; the negative and equalizer leads are connected through their switches to bus-bars located under the floor near the exciters. With this arrangement there is little chance for a short circuit on the exciter connections.

On the generator panel are the following: one indicating wattmeter *9*; one ammeter *10*; one voltmeter *11*; one recording wattmeter *12*; one double-pole double-throw potential reversing switch *13*, for the indicating wattmeter; one four-point receptacle with plug *14*, for synchronizing connections; a hand wheel and chain (back of board), for operating the generator field rheostat; one single-pole single-throw carbon-break field switch *15*, with discharge clips; one double-pole double-throw switch *16*, for controlling a small motor that operates the engine governor; one triple-pole single-throw oil switch, mounted back of the board and operated by handle *17*; one current transformer, for the wattmeters and the ammeter, and two potential transformers—the three transformers being located on the back of the switchboard.

The outgoing-line panel is provided with three ammeters *18*, one for each phase; one triple-pole single-throw oil switch, mounted on the back of the board and operated by the handle *19*; and three current transformers for the ammeters. The current transformers are located on the back of the board. The oil switch has an overload release coil, which is encased in the cylindrical box just under the switch handle *19*.

59. The principal connections for the switchboard just described are shown in Fig. 27, the switches and instruments being numbered the same as in Fig. 26. On the exciter panel, Fig. 27, are the main positive bus-bar, the potential buses, and as many other pairs of buses as are needed to operate small direct-current auxiliary motors. One pair of such buses are shown at *A* near the center of the panel; they would be extended across the generator panel if needed. The potential buses are to enable any exciter, where several



Main Bus-Bars
Trip Coils
Current Transformers
Positive
Bus-Bar
Potential Buses
Synchronizing
Buses
A
Ground Bus
Potential Transformer
To Fld Rheostat
Start
Run
Syn Plugs
B
Out Going Line
Voltage Detectors
Lightning Arresters
To Station Lights
Negative Bus-Bars
Equalizer
Exciter Panel
Generator Panel
Line Panel
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

are used, to be connected to the voltmeter on the bracket by means of the voltmeter plug *5*; hence, these buses extend only across the exciter panels. The dotted lines to switches *7* and *8* represent connections made only on one exciter panel in each switchboard. The synchronizing connections, or buses, also cross back of the exciter panel on their way from the generator panels to the synchronizer.

Three main bus-bars extend across the top of the generator panel and the outgoing line panel, and farther down on the generator panel are the synchronizing buses and a bus for grounding various instruments. The synchronizing plugs are for use in receptacle *14*. One plug is used for starting and the other for running, and the difference in the connections of the two is shown by the lines across the plugs. If oil switch *17* were operated by a small motor, as is sometimes done, it might be necessary to extend bus-bars *A* from the exciter panel across the back of the generator panel. Double-pole double-throw wattmeter switch *13* is normally held by a spring in the lower contacts, so that the instrument is connected as a wattmeter; but by throwing the switch up, the connections are so changed that the instrument will indicate the wattless component, thus serving to detect the presence of cross-currents when the generator is operating in parallel with others. Connections for switch *16* for controlling the engine-governor motor *B* are also shown; a spring holds the switch open until the attendant closes it either way momentarily, to change the speed of an engine. This attachment is used only in very large plants. An automatic attachment is also sometimes used with the generator oil switch and the engine governor, so that the oil switch will open and the governor will be specially adjusted in case of excessive overload. The transformers are used to reduce the current and pressure for the instruments.

On the line-panel diagram are shown the connections of the line oil switch *19* with its *release*, or *trip*, *coils*, and also those of the current transformers and the ammeters. There are also shown the connections for voltage detectors and lightning arresters, which are designed for mounting on the

wall near the place where the line enters the building. Between the detectors and the arresters are three single-pole double-blade switches, one switch in each phase; one blade of each switch connects a phase of the line to the lightning arrester, and the other connects to the conductor leading to the switchboard. The voltage detectors indicate, before the main switch *19* is closed, whether other generators are connected to the same line.

ELECTRIC-RAILWAY STATION EQUIPMENT

(PART 2)

SUBSTATION EQUIPMENT

1. Long-distance transmission is usually affected at pressures too high to be used without transformation. Moreover, the energy is nearly always transmitted by alternating current, while the prevailing method of operating street railways has been by direct current at 500 to 600 volts. The transformations from high-tension to low-tension alternating current of the same or different frequency, and from low-tension alternating current to direct current, are made in what are known as **substations.**

If the output from the substation is wholly alternating current, static transformers with the necessary controlling apparatus are usually all that is necessary. For supplying direct current from substations, rotary converters are generally used, although if the frequency of the incoming current is high, motor-generators are preferable. A *motor-generator* for the transformation just mentioned consists of an alternating-current motor direct-connected to a direct-current generator. Motor-generators are used more in European countries than in the United States. On high frequencies of 60 cycles or more, they allow closer regulation of the direct-current voltage than is possible with rotaries; they also completely separate the two systems—direct and alternating. However, for frequencies not exceeding 40 or

50 cycles per second and for places where it is not essential to keep the alternating-current system entirely disconnected from the direct-current system, rotary converters are preferable, because they are more efficient, occupy less floor space, and are less expensive, even when the motor of the motor-generator can be wound for the full line pressure, thus avoiding the use of step-down transformers.

The equipment of a substation may be conveniently considered under three heads, namely: Apparatus for Controlling the Incoming Current; Apparatus for Transforming the Current; and Apparatus for Controlling the Outgoing Current.

APPARATUS FOR CONTROLLING THE INCOMING CURRENT

2. The apparatus for controlling the incoming current is generally grouped on a high-tension switchboard, and is separated, at least so far as the high-tension parts are concerned, from the devices controlling the outgoing current. Its arrangement is very similar to that described for the outgoing line in the main station. The incoming lines should first pass through a circuit-breaker or main switch, so that all current may be cut off from the station. Oil switches are used in many cases, and are so arranged that they may be opened either by hand or automatically whenever the current exceeds the allowable amount. When arranged in this way, the one device serves both as a main switch and as a circuit-breaker. Switches of the air-break type and those in which the arc is broken in a confined air space are also made to operate automatically in case of overload. All of these types are in common use for protecting the incoming lines.

3. Time-Limit Relay.—Rotary converters or other synchronous machines in a substation will fall out of synchronism whenever the circuit opens, and much time is required to get under headway again. For this reason, it is undesirable to have the automatic switches act unless absolutely necessary in order to prevent burn-outs. Momentary

overloads, though very excessive, will seldom injure electrical machinery, but will trip ordinary circuit-breakers and thus shut down the station. To avoid this occurrence a **time-limit relay** is used with the automatic circuit-opening device. This relay delays the opening of the circuit-breaker. If the overload is only momentary, the relay goes back automatically to its initial position and the circuit is not opened. If the overload continues, the relay will open the circuit-breaker.

4. In Fig. 1 is shown a **Westinghouse relay,** in which the time-limit feature is regulated by means of a dashpot. A solenoid *a* is connected to the secondary of a current transformer whose primary carries the line current, and a movable core *b* rests on a lever *c* pivoted at *d*. To the end of the lever is attached a rod *e* which carries the piston of a dashpot *f*. The lever, counterbalanced by a weight *g*, is normally held in the position shown in the figure, by the weight of the core resting on it. An arm *h*, also pivoted at *d*, carries contact springs *k*, *l*, and its position can be adjusted, up or down, by an adjusting screw on the cover of the instrument. The lever carries a contact piece *m*, that connects *k*, *l* if the lever rises far enough. When the current in the solenoid exceeds the allowable amount, the core is lifted, thus allowing the counterweight to raise the lever. The movement of the lever is controlled by the dashpot, and the time during which the overload may exist before the circuit is

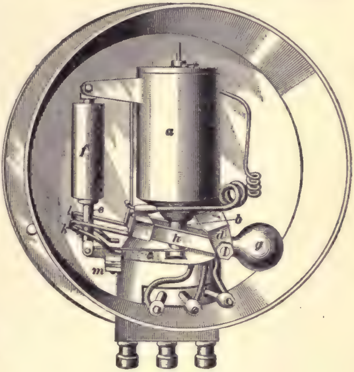


FIG. 1

opened is determined by the position of the arm *h*. When the lever has moved high enough to close the circuit between the springs *k* and *l*, the circuit-breaker is tripped and the main circuit opened. Should the overload pass off before the time limit is reached, the core drops back and the lever is forced down before the circuit between the springs *k* and *l* is completed.

By equipping all the circuit-breakers on a system with time-limit relays, and arranging them so that the relays nearest the main station will be the last to open, a shut-down of the entire station due to a short circuit on some distant part can be avoided. The circuit-breaker nearest the defect should be the first to act.

5. Reverse Current Relay.—In a large distributing system with several stations connected to the same feeders or lines, the opening of a switch or circuit-breaker may permit current to flow back through some apparatus with disastrous results. For example, let *A*, Fig. 2, represent

FIG. 2

a main station supplying three-phase current to substation *B* through two three-wire cables *c* and *d* in parallel. Parallel circuits are frequently run between stations, so that the service need not be interrupted by an accident to one cable. If a short circuit should occur on one of the cables, as at *f* on cable *c*, the main-station circuit-breaker on that cable would open, but current could still flow from the main station over

cable *d*, through the substation bus-bars, and back on cable *c* to the short circuit. This current would open the main-station circuit-breaker on cable *d*, and thus shut down the whole system. In order to prevent this, **reverse-current relays** are installed at the ends of the feeders at the substation; these relays trip the circuit-breakers the instant the flow of energy through any of the cables reverses.

6. In Fig. 3, *A*, *A* are circuit-breakers, and *B*, *B*, reverse-current relays. These relays are similar in construction to small direct-current motors having laminated fields. The field windings are excited by current from the secondaries of two potential transformers *t*, *t'*, and the armatures are supplied with current from the current transformers *c*, *c'*. The movement of the armatures is limited by an arm playing between two stops, as shown. When the flow of energy is in its normal direction from the cables to the bus-bars, the arm of the relay bears against the lower stop, which is insulated; but if the flow of energy reverses, the armature at once swings around in the opposite direction until the arm touches the upper stop, thus closing the battery circuit and tripping the circuit-breaker.

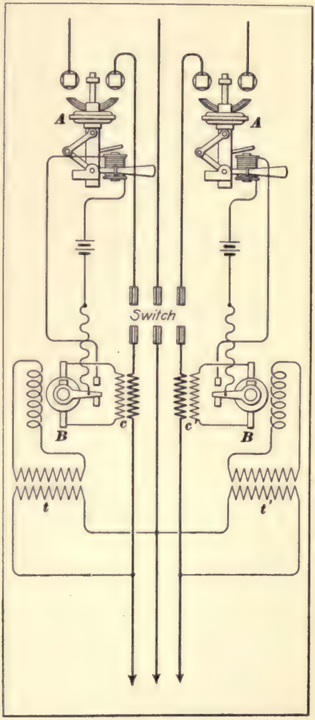


FIG. 3

7. When storage batteries are used in connection with a railway system, they are usually connected to the circuit in parallel with the direct-current generators or the rotary converters. In case the voltage of the generators should fall, current from the battery would feed back through the machine with more or less serious results. To prevent this reversal of current, some form of reverse-current circuit-breaker is used.

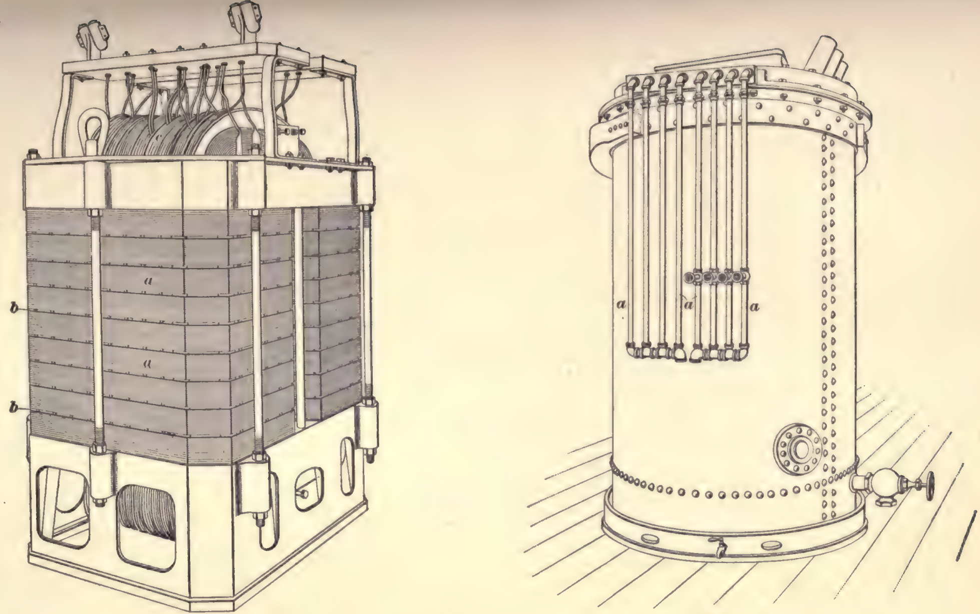
APPARATUS FOR TRANSFORMING THE CURRENT

STATIC TRANSFORMERS

8. Compared with the transformers used in ordinary local lighting and power distribution, substation transformers are usually of very large output. While their efficiency is very high, yet on account of the comparatively small radiating surface that they present to the air, it is necessary to provide special means for getting rid of the heat; this is accomplished either by means of an air blast or by water that circulates through a coil of pipe placed in the upper part of the transformer case. When water pipes are used, the transformer case is filled with oil, and as the heated oil rises to the upper part of the case it is there cooled by the water in the pipes, and descends to the lower part; a continuous oil circulation is thus kept up that carries the heat away from the coils and core and transmits it to the circulating water.

9. Fig. 4 illustrates a **Westinghouse 2,250-kilowatt substation transformer.** In (*a*) is shown the coils and core assembled before being placed in the case. The core laminations *a*, *a* are built with openings *b*, *b* at intervals, so that the oil can circulate through the core and conduct the heat from the internal parts. The primary and secondary coils are each wound in several sections in the form of large flat coils, which are then sandwiched together, each section of the secondary lying between two sections of the primary, making a construction that reduces magnetic leakage, and at

7



(a) Fig. 4 (b)

the same time reduces the voltage generated in any section of the winding. The ends of the coils project beyond the laminations at the top and bottom, as shown at *c*, and the terminals of the coils lead to a terminal board mounted on top.

The transformer is placed in a cylindrical tank made of riveted boiler plate, as shown in Fig. 4 (*b*), and is completely submerged in oil. Four coils of pipe placed in the upper part of the tank are connected in parallel by pipes *a*, *a* attached to common inlets and outlets. Each coil is provided with a valve, so that in case it becomes defective, it can readily be cut out without disturbing the flow of water through the others. This transformer, being of very large output, has an efficiency of 98.63 per cent. at full load, 98.2 per cent. at half load, 97.2 per cent. at quarter load, and 98.5 per cent. at one-half overload.

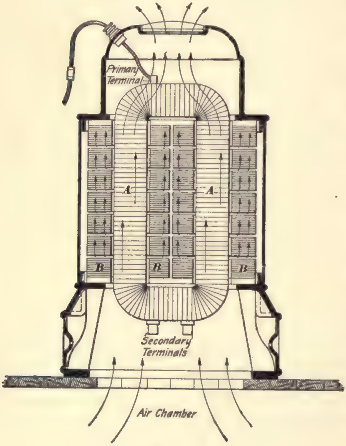


Fig. 5

Fig. 5 shows a sectional view of an **air-olast transformer** of the General Electric type. The construction of the coils A, A and cores B, B is such that air spaces are left between the parts, and the transformer is mounted over an air chamber in which about ½ ounce air pressure is maintained by motor-driven fans. The air passes through the openings in the core, between the coils, and out at the top and sides; suitable dampers are provided by means of which the flow can be regulated. This makes an efficient and cleanly method of cooling large transformers.

Fig. 6 shows a group of nine air-blast transformers of 150 kilowatts each. A motor-driven fan is mounted at each end of the chamber, and either fan has sufficient capacity to

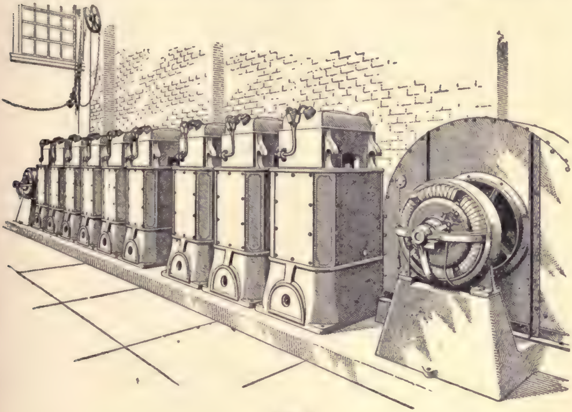


FIG. 6

keep the transformers cool, thus providing a reserve blowing outfit in case one breaks down. The power required to operate the fans does not usually exceed one-tenth of 1 per cent. of the transformer output.

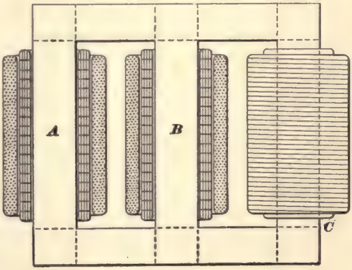


FIG. 7

10. Polyphase Transformers.—The use of three-phase current for transmission saves not only in material but in space required for the transformers. These and other considerations have led to the adoption of three-phase currents instead of single- or two-phase currents for most transmission systems.

In Fig. 7 is shown the general arrangement of a **three-phase core-type transformer.** The primary and secondary coils, which are wound on the cores A, B, C, may be connected Y or $\triangle$. The magnetic flux in the core follows the same changes as the currents. Each core acts alternately as the return path for the flux in the other two cores, just as each line wire acts alternately as the common return for the other two in a three-phase line. The iron in the core is thus worked to better advantage than when three separate single-phase transformers are employed.

A two-phase transformer could be made by winding coils on cores A and C and leaving core B vacant. In this case, all the flux passing through cores A and C would return through B, which should be $\sqrt{2}$, or 1.414, times the size of either A or C.

ROTARY CONVERTERS

11. The transformation from alternating current received at a substation to the direct current required by the car motors is usually effected by means of **rotary converters.** The nature of the current flowing in the armature conductors of a converter is peculiar; the two currents, direct and alternating, are opposed to each other in direction during a larger part of the cycle, and the heating of the conductors is due either to the excess of the one over the other or to the difference between the two. A single-phase converter will heat more than if the same machine were run as a direct-current dynamo with the same output, but polyphase converters will heat less. Calling the output obtainable from a direct-current dynamo with a certain heating effect *1*, that obtainable from the same machine equipped with collector rings and run as a rotary converter would be approximately as follows: As a single-phase converter, .85; as a three-phase, 1.34; as a two-phase, four-wire, 1.64; and as a six-phase, 1.96—the heating effect being the same in all cases. This has led to the use of polyphase converters, those for six phases being quite common, especially where the machines are of large output. If the current lags behind

the electromotive force, the values will be less than those just stated; the values also vary somewhat according to the design of the converter.

12. Connections for Six-Phase Rotary Converters. Six phases may be easily obtained from three phases by

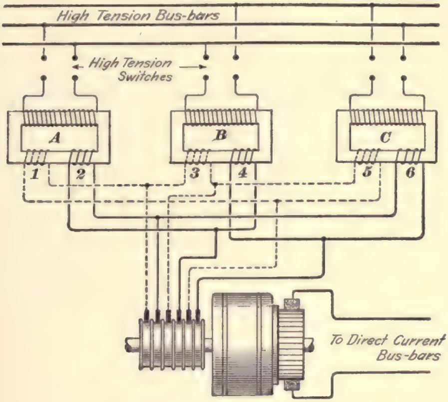


Fig. 8

providing each of the three transformers with two secondary coils, as shown in Fig. 8. Each set of coils—*1*, *3*, and *5*, and *2*, *4*, and *6*—is connected Δ, one group being reversed as regards the other, thus giving the double-delta arrangement indicated in Fig. 9. The collector rings are attached to the points *a*, *b*, *c*, etc., thus supplying the converter with six currents differing in phase by 60°. The use of six phases introduces some additional complication in the connections between the transformer secondaries and the converter, and also requires six collector rings, but this extra complication is more than offset by the increased output of the converters. Sometimes, switches are inserted between the transformer secondaries and the converter, but more often

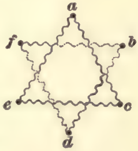


Fig. 9

the switching is done on the primary side, because the secondary current is usually large and the switching devices would have to be correspondingly heavy.

13. Voltage Regulation of Rotary Converters. Usually it is necessary to arrange converters so that their direct-current voltage can be increased with increase of load, so as to keep the voltage constant at distant points on the system. By changing the field excitation, the voltage of the

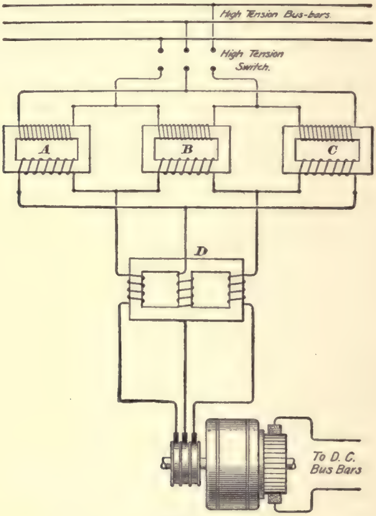


FIG. 10

direct-current side can be raised or lowered within certain limits, owing to the change of phase difference between the current and the electromotive force on the alternating-current side. This change is explained in another Section in connection with synchronous motors. Increased field excitation with increase in load is usually obtained by providing the machine with a compound field winding similar to that on a compound-wound direct-current dynamo. If the

load were not of a suddenly fluctuating character, the necessary field regulation could be obtained by adjusting the rheostat in the shunt-field circuit, and a series-field winding would not be needed.

In order to increase the effect of the change of field strength on the phase relation of the alternating current, reactance coils are used between the step-down transformers and the collector rings. Fig. 10 shows such connections for a three-phase converter; A, B, and C are the step-down transformers, and D is a laminated core on which the three reactance coils are wound.

14. Starting Rotary Converters.—The methods of starting rotary converters may be divided into two classes: those which require synchronizing devices, and those which do not require these devices. Starting by one of the former methods usually requires a little more time, but is less severe on the system because less starting current is required. It is because of the ability to start without a shock to the system that methods employing synchronizing devices have been most largely in use heretofore, but the tendency in modern practice is to start in the least possible time.

15. The methods employing synchronizing devices are: starting from the direct-current end as direct-current motors, and starting by means of small induction motors connected to the converter shafts. Direct current for starting may be obtained from other rotaries already in operation, from a small motor-generator set consisting of an induction motor and a direct-current generator installed purposely to obtain starting current, or from storage batteries if they are in use.

When the converter is started from the direct-current side, it is necessary to insert a resistance in the armature circuit. Fig. 11 shows a type of starting rheostat used for this purpose. On account of the unequal lengths of the switch clips, the three sections of the resistance are successively short-circuited as the switch is closed. As the converter starts unloaded, it comes up to speed quite rapidly, and a simple switch giving four or five resistance steps is sufficient.

Converters that are already in operation are frequently depended on to furnish direct current to start additional machines. The additional machines do not usually have to be started until those already in operation are overloaded, and then it may be necessary to get another converter into operation in the shortest possible time. Perhaps by this time the direct-current load is so heavy and so variable that it is difficult to get a direct voltage steady enough to synchronize the new machine quickly and safely; hence, this method is sometimes objectionable.

16. One large manufacturing company builds a small induction motor for each converter, mounting the armature

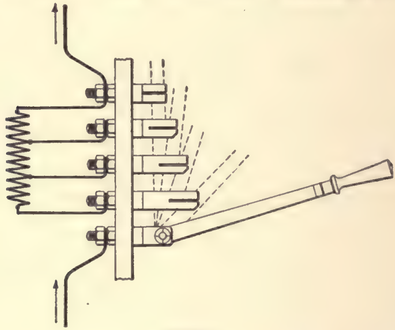


Fig. 11

of the motor directly on the converter shaft. The motor is designed to run the converter a little too fast, and the speed is held down to synchronism by a synchronizing rheostat connected across a phase of the alternating-current end of the converter, thus putting a slight load on the machine. There are several taps on the synchronizing rheostat, so that it may be adjusted for different converters or for the same converter under different conditions. A separate motor for each converter would be an expensive method where there are a number of such machines in a substation; it would be cheaper to install a motor-generator set, if direct current were not available from any other source.

17. If an alternating electromotive force is applied directly to the collector rings of a polyphase converter, the machine will start and will come into synchronism automatically. This method is much used, but some precautions are necessary. If the full alternating electromotive force were applied to the rings at once, a very high starting current would be drawn from the system, with resulting severe drop of voltage and disturbance to all other machinery in operation on the same circuit. In order to lessen the shock, a double-throw switch and extra connections from the step-down transformers are so arranged that half voltage can be thrown on the collector rings at first and full voltage after the machine is under some headway. Fig. 12 shows such an arrangement. With low frequencies, say 25 cycles, starting from the alternating-current end with this arrangement does not cause severe disturbances.

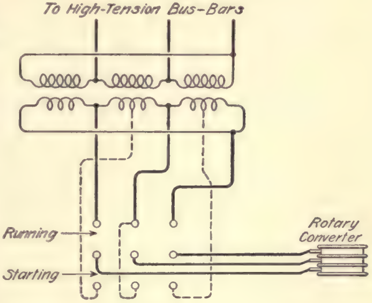


FIG. 12

18. Alternating current through the armature conductors sets up a rotating field about the armature surface, exactly as is done about the field of an induction motor. This rotating field sets up eddy currents in the pole faces, and the reaction between these currents and the rotating field is sufficient to start the armature. The rotating field also causes a rapidly changing flux to be set up in the field poles, and this flux causes a high electromotive force to be generated in the field coils. If the coils remained in series, thus combining the electromotive forces of all of them, their insulation might be destroyed. For this reason, it is customary to install a field break-up switch by which

the coils can be disconnected from each other while starting with alternating current.

19. When the alternating current is first switched on to the collector rings, it reaches all parts of the armature circuits, including the direct-current brushes; and the direct-current voltmeter, if of the Weston or other similar type, will not show a deflection, but the needle will tremble. As synchronism is approached, the needle will vibrate, the vibrations becoming slower and slower until, at exact synchronism, the needle remains steady, showing a constant direct voltage. When nearing synchronism, the field break-up switch should be closed, thus connecting the fields across the direct-current circuit. If this connection is not made at the proper instant, the fields will build up wrong and another trial must be made. The direction in which the fields build up depends on which side of zero reading the voltmeter needle is when the switch is thrown in. This uncertainty is an objection to starting in this way, but is not serious, as one or two trials should bring the desired result.

20. Another method of starting without the use of synchronizing devices is to start as a direct-current motor and, by adjusting the field rheostat, obtain a speed slightly above synchronism. After reaching this speed, all connections with the direct-current end are opened and the full alternating voltage is switched on to the collector rings while the armature is still near synchronous speed. The converter will at once pull into step and will not require a heavy current to do so.

21. Synchronizing Rotary Converters.—Rotary converters and synchronous motors are synchronized with the line electromotive force in the same way that an alternator is synchronized with the bus-bar electromotive force. Lamps, voltmeters, or synchronizers may be used to indicate the point of synchronism. Fig. 13 shows connections for a **Lincoln synchronizer.** When the pressure is more than 400 or 500 volts, potential transformers should be used in connection with the synchronizer; the figure shows connections

for a low-potential system where transformers are not necessary. Synchronizing lamps are also provided, enough lamps being connected in series to stand the voltage. If converter No. 2 were to be synchronized, plugs would be inserted at *a*, *b*, and *e*, thus connecting the upper terminals of the synchronizer to the bus-bars and the lower terminals to the corresponding phase of the converter. When the synchronizer is used on pressures somewhat above those for

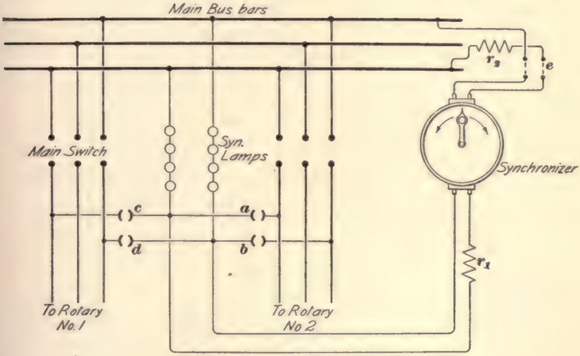


FIG. 18

which it is made, resistances must be inserted as shown at r_1 and r_2.

Automatic synchronizers are sometimes used; they are generally based on the use of magnets connected to the bus-bars and to the starting machine in much the same way as are synchronizing lamps. When synchronism is attained, the magnets close a circuit that controls the main switch.

APPARATUS FOR CONTROLLING THE OUTGOING CURRENT

22. The controlling devices for the alternating current entering the substation and those for the direct current leaving it differ materially from each other and are grouped at different parts of the switchboard, or possibly on separate switchboards. The delivered current is controlled by the same kind of devices used in a main station where the working current is generated. Rotary converters are operated in parallel, and are connected on the direct-current side in exactly the same way as direct-current generators. If the converters are compound wound, an equalizer connection must be used.

LOCATION AND GENERAL ARRANGEMENT OF SUBSTATIONS

LOCATION

23. The choice of the locations for railway substations depends so much on local conditions that few definite instructions can be given. Many an extensive network of railway lines—now operating as one system with one or more central stations and numerous substations—was made up by the consolidation of smaller systems; the stations and substations were not always located with a view to the complete development as it exists today, and it is quite probable that other similar consolidations will occur in the future. The best that can be done is to estimate as nearly as possible both present conditions and probable growth of the system, and to locate the substations so as to obtain the greatest economy. There must be considered the cost of attendance and of distributing the energy both to the substations and from them to the car motors; this cost includes both the interest charges on the necessary investment and the energy lost in the distribution system. The fewer the number of substations on a given system, the greater their size and the

less their combined cost and the cost of attendance; but with few substations located far apart, the cost of copper and the energy losses will probably both be increased. The substations do not have to be located with reference to coal or water supply, and the price of real estate becomes a comparatively small item, because of the very large output compared with the space occupied. Substations can also be placed in locations where power plants would not be permitted on account of the accompanying smoke and dirt; hence, their location may be very nearly as determined from the foregoing considerations of economy.

GENERAL ARRANGEMENT

24. Fig. 14 illustrates the interior of a substation in Buffalo, New York, supplied with power from a Niagara

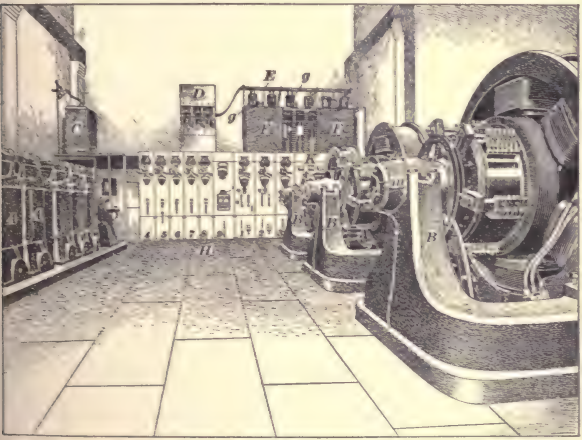


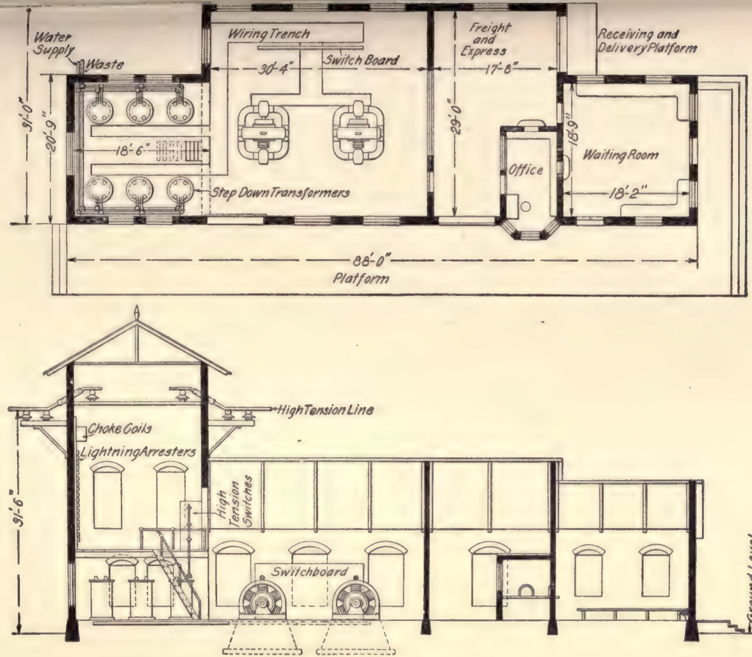
FIG. 14

power plant. All the machinery and controlling devices are here placed in one room, and a single attendant only is required. The building is fireproof, being erected expressly

for a substation, and is provided with a hand-operated overhead traveling crane for handling the machinery during installation or when making repairs. The step-down transformers A are ranged along one side, and the three rotary converters B along the other. Each converter has a capacity of 400 kilowatts and is supplied by a group of three 150-kilowatt air-cooled transformers, the secondaries of which are connected to the converter; air-blast reactance coils, placed behind the transformers, are inserted between the transformers and the converters, in order to permit voltage regulation by variation in field strength. The converters are six-pole machines supplied with 25-cycle current, and run at 500 revolutions per minute.

The incoming current at 10,000 volts enters the basement in a lead-covered cable and passes through a hand-operated oil switch C, by means of which all power may be cut off from the station. From the oil switch, the current passes through the high-tension circuit-breakers located on the switchboard D and provided with time-limit relays. From the circuit-breakers, the current goes to the high-tension bus-bars E and from there to the three high-tension oil switches F mounted in a brickwork casing. In the figure, one of the iron covers is removed, showing the three cells of one switch. Each switch controls the current in the primaries of a group of three transformers supplying a rotary converter. The potential transformers for supplying current to the voltmeters and synchronizing lamps are shown at g on top of the oil switches. The high-tension switches and circuit-breakers are on a gallery, and just below them is the switchboard H. The three alternating-current panels K at the right contain the handles for operating the oil switches F as well as the alternating-current measuring instruments. Everything on the switchboard is thoroughly insulated from the high pressure.

From the high-tension switches F, the current passes to the primary coils of the transformers, from which the secondary current passes to the collector rings of the converters. The direct current from the converters passes to the panels



Water Supply
Waste
Wiring Trench
Switch Board
30'-4"
Freight and Express
17'-8"
Receiving and Delivery Platform
31'-0"
20'-9"
18'-6"
29'-0"
18'-9"
Office
Waiting Room
18'-2"
Step Down Transformers
88'-0"
Platform
High Tension Line
Choke Coils
Lightning Arresters
31'-6"
High Tension Switches
Switchboard
Ground Level

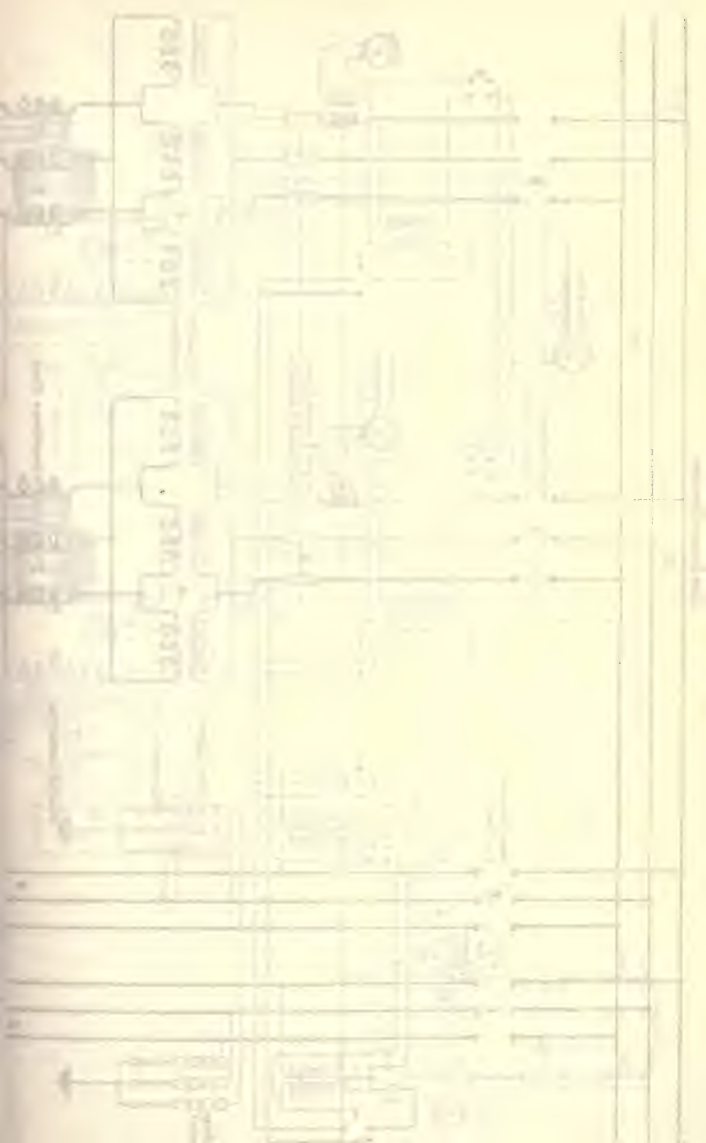
Fig. 15

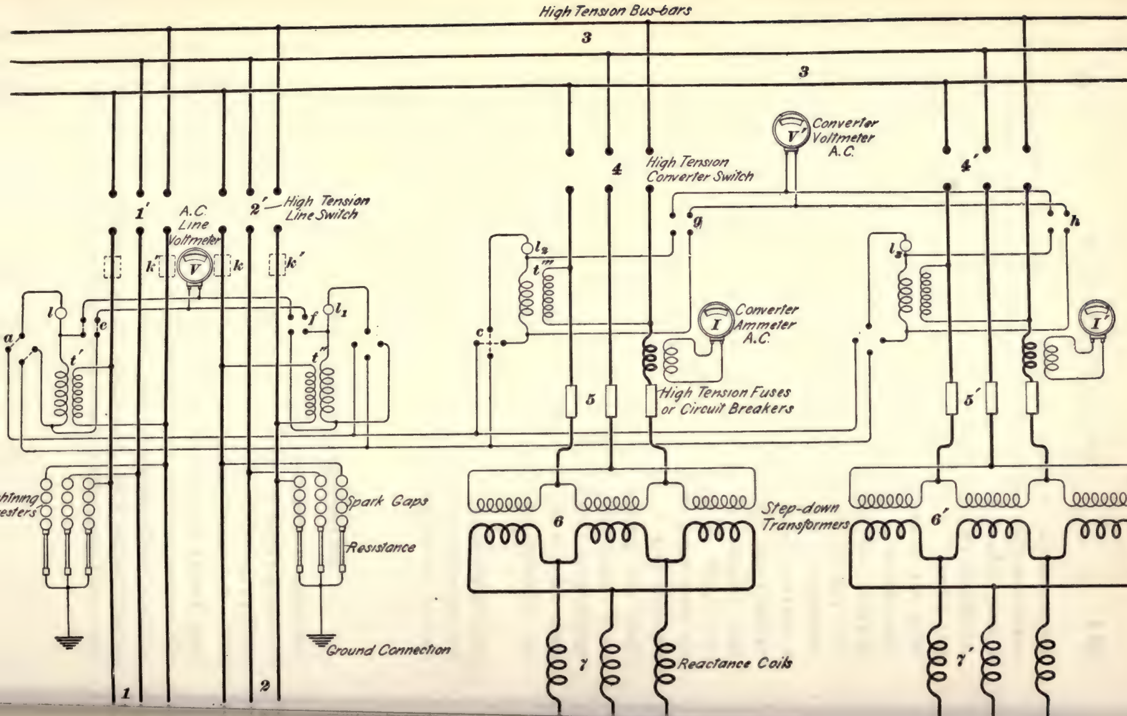
1, 2, 3, each of which is provided with a direct-current ammeter and circuit-breaker in addition to the main switches. The outgoing feeders are connected to the feeder panels *4, 5, 6*, etc., each of which is provided with an ammeter, circuit-breaker, and main switch. Panel *9* carries an ammeter that measures the combined output of the converters, a voltmeter for measuring the direct-current voltage, and a recording wattmeter for registering the output of the substation. The voltmeter can be connected to any converter by means of plug connections on each converter panel. The subbase of each converter panel carries a single-pole switch for the field, and a double-pole transfer switch for connecting the converter to be started with the starting switch on the subbase of panel *9*. Each converter is provided with an iron-clad magnet *m* mounted on the end of the bearing casing. A current is sent through this magnet at regular intervals, thus making the shaft oscillate back and forth, thereby keeping the brushes from wearing furrows in the commutator. Mechanical devices that have the advantage of not requiring any current for their operation have also been designed for maintaining an oscillation of the shaft.

Fig. 15 shows the plan and elevation of a typical substation for an electric railway. The arrangement of the water-cooled transformers, rotary converters, etc. is clearly shown, so that further comment is unnecessary.

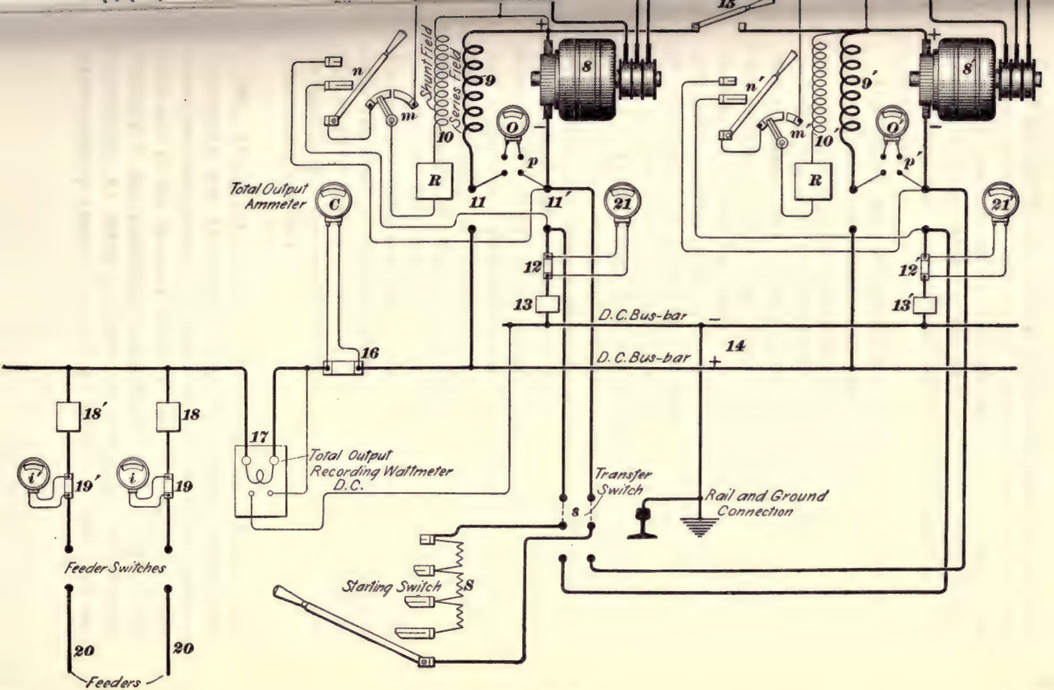
CONNECTIONS FOR SUBSTATIONS

25. It is impossible to give any scheme of connections that is applicable to all substations. Fig. 16 shows a method that might be used for a substation receiving its energy from either of two high-tension transmission lines *1, 2*. The station has two compound-wound three-phase rotary converters *8* and *8'*, and it is assumed that both are never idle at the same time, so that there is always direct current available for starting an idle converter. If it should happen that both converters were shut down at the same time, they





High Tension Bus-bars
3
3
Converter Voltmeter A.C.
High Tension Converter Switch
4
4'
High Tension Line Switch
A.C. Line Voltmeter
1'
2'
Converter Ammeter A.C.
High Tension Fuses or Circuit Breakers
5
5'
Step-down Transformers
6
6'
Spark Gaps
Resistance
Ground Connection
Reactance Coils
7
7'
1
2



Shunt Field
Series Field
Total Output Ammeter
D.C. Bus-bar
D.C. Bus-bar
Total Output Recording Wattmeter D.C.
Transfer Switch
Rail and Ground Connection
Starting Switch
Feeder Switches
Feeders

FIG. 16

could be started by starting up the alternator in the main station, with the converters connected to the line, and allowing the converters and the alternator to come up to speed together. Many of the connections could be made in other ways than those shown and still give practically the same results.

The wiring may be considered in two sections: that for alternating current between the incoming lines and the converters, and that for direct current between the converters and the outgoing feeders *20, 20*. Current enters the station through either or both incoming lines, passes through the switches *1′, 2′* to the bus-bars *3*, thence through the switches *4, 4′* and the fuses or circuit-breakers *5, 5′* to the primaries of step-down transformers *6, 6′*. Switches *4, 4′* may be provided with automatic tripping devices, in which case neither fuses nor circuit-breakers would be needed at *5, 5′*. Transformers *6, 6′* step down the voltage to that needed by the converters to secure the required direct-current voltage; for example, if 550 volts are required at the direct-current end, the alternating voltage at the collectors rings must be $550 \times .612 = 337$ volts, approximately. Between the transformer secondaries and the converters are the reactance coils *7, 7′*, which enable the compound winding of the converters to affect the regulation.

From the converters, the 550-volt direct current passes through the main switches *11, 11′* to the bus-bars *14*. The negative bus-bar is connected direct to the track rails, while the positive bus-bar is connected to the feeders through the wattmeter *17*, the circuit-breakers *18, 18′*, and the single-pole feeder switches.

26. Connections for Synchronizing.—Since these converters, Fig. 16, are to be started by direct current, they must be synchronized. Connected to each of the incoming lines and to the primary terminals of the step-down transformers *6* are potential transformers t', t'', t''', etc. The secondaries of these transformers are connected through synchronizing lamps, l, l_1, l_2, l_3 to plugs, so that any two

secondaries may be connected in series. For example, in synchronizing converter *8*, plugs *a* and *c* may be put in as shown by dotted connections, so that when the converter is in synchronism with the line electromotive force, lamps l and l_2 will glow at full brilliancy.

27. Voltmeter Connections.—By means of plugs *e*, *f*, Fig. 16, voltmeter *V* can be made to indicate the voltage of either high-tension line, and by plugs *g*, *h*, voltmeter V' can be made to indicate the voltage of the alternating end of either converter. The voltage of the direct-current side of the converters is indicated by the voltmeters *O*, O' connected to the voltmeter plug receptacles *p*, p'. The voltage of the converter can thus be compared with that of the line or the direct-current bus-bars before it is fully connected to either.

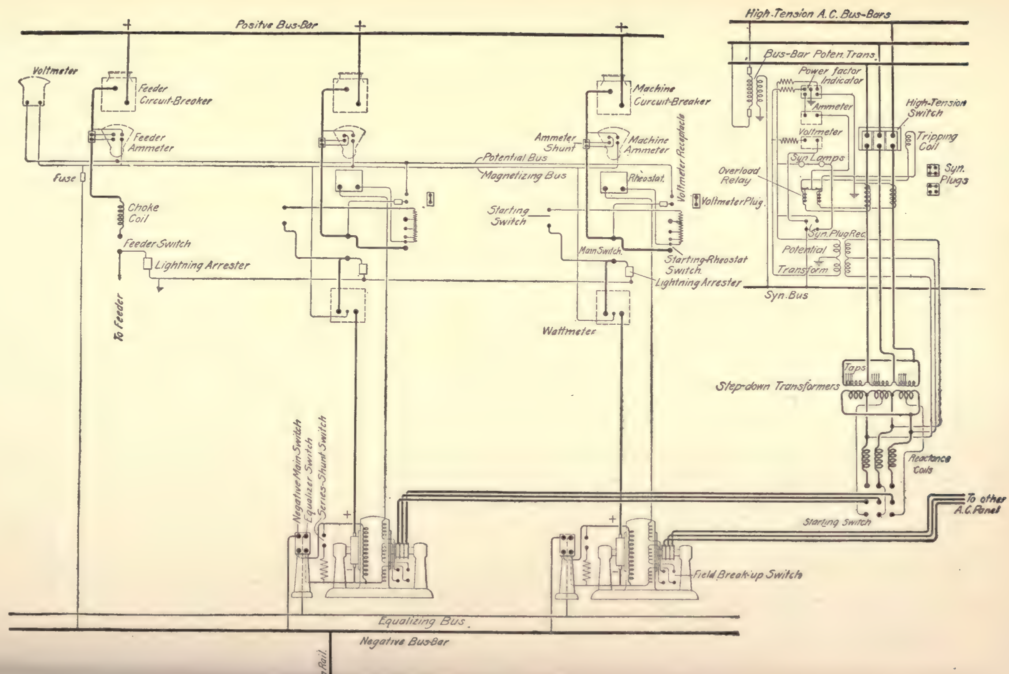
28. Ammeter Connections.—Each converter, in Fig. 16, is provided with an ammeter *I* connected to the secondary of a current transformer inserted between the switch *4* and the transformer primaries. In some cases, an ammeter is inserted in each line wire, especially in large installations, though this is not absolutely necessary. In some cases, also, ammeters are placed on the incoming lines, series transformers, of course, being used so as to thoroughly insulate the instruments from the high-tension line. The direct-current side of each converter is provided with an ammeter *21*, connected across a shunt *12*. Ammeter *C*, connected across shunt *16*, indicates the total direct current. The feeders are provided with feeder ammeters *i*, i' connected across the shunts *19*, *19'*.

29. Circuit-Breakers.—In this case, the incoming lines are not equipped with automatic circuit-breakers, though, if the substation formed part of a large network, circuit-breakers would likely be inserted at *k k'*, Fig. 16, and would be equipped with reverse-current and time-limit attachments. On the direct-current side, each converter is provided with a circuit-breaker *13*, *13'* connected between the converter and the bus-bars. Each feeder is also provided with a circuit-breaker, indicated at *18*, *18'*.

30. Equalizer Connection.—The positive brushes of the converters, Fig. 16, are connected by means of an equalizer cable and the equalizer switch *15*. Note that the equalizer connects the two brushes to which the series-field windings are attached.

31. Shunt-Field Connections.—One end of the shunt field, Fig. 16, connects to the + brush, and the other to one terminal of the field rheostat *R*. The other rheostat terminal connects to the blade of the field switch *m*, which is in the position shown in the figure when the converter is in operation. Switch *n* allows the shunt field to be excited either from the direct-current bus-bars or from the converter itself.

32. Starting and Synchronizing.—Suppose that converter *8′*, Fig. 16, is in operation and is supplying current to the direct-current bus-bars, and that converter *8* is to be started, synchronized, and thrown in parallel with *8′*. Before starting, switches *4*, *11*, *11*,′ *15*, *n*, and *m* are open. Close the equalizer switch *15*; place field switch *m* in the position shown in the figure, and close switch *n* until the blade makes contact with the long clip. The shunt field *10* of converter *8* will then be excited by a current flowing from *8′* through the equalizer, the field, rheostat *R*, switches *m* and *n*, and back to the negative bus-bar. Close switch *11*, thus allowing current to flow through the series field *9*. Throw the transfer switch *s* to the upper contacts, and close starting switch *S* gradually through the several contacts. A current will flow from *8′* through the equalizer, the armature of *8*, the transfer switch, and the starting resistance, back to the negative bus-bar, thus starting converter *8* as a direct-current motor. Insert the synchronizing plug as shown by the dotted lines at *c*. The speed of *8* can be adjusted by moving the field rheostat *R*, and when the point of synchronism is attained, as indicated by the lamps l, l_2, switch *4* is closed, after which the converter will run as a synchronous motor. Switches *s* and *S* should then be opened, the voltage of *8* should be adjusted until it equals or slightly exceeds that of the bus-bars, and then switch *11′* should be closed. Switch *n* should



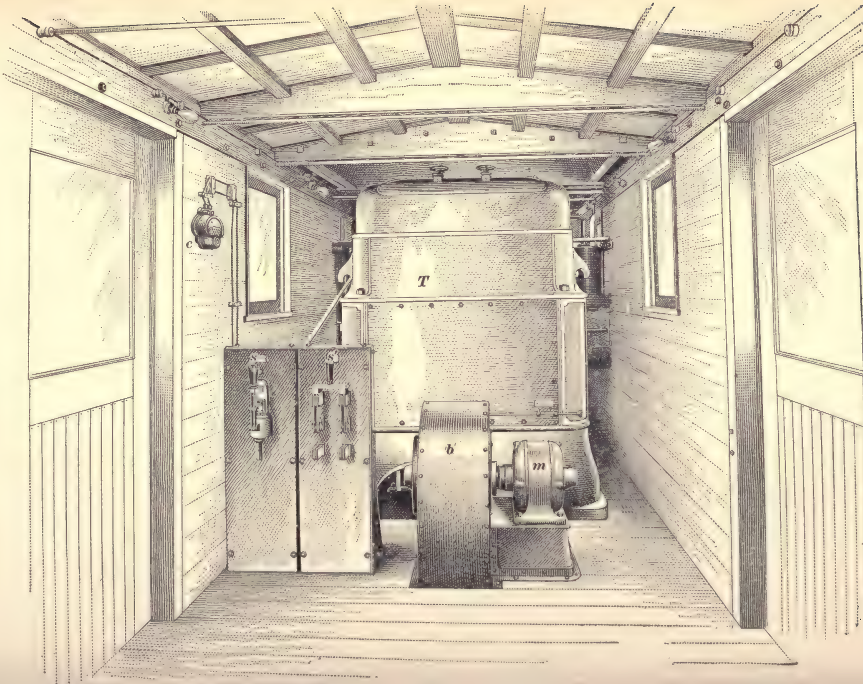
Positive Bus-Bar
Voltmeter
Feeder Circuit-Breaker
Feeder Ammeter
Fuse
Choke Coil
Feeder Switch
Lightning Arrester
To Feeder
Machine Curcuit-Breaker
Ammeter Shunt
Machine Ammeter
Potential Bus
Magnetizing Bus
Rheostat.
Voltmeter Receptacle
Voltmeter Plug.
Starting Switch
Main Switch.
Starting-Rheostat Switch.
Lightning Arrester
Wattmeter
High-Tension A.C. Bus-Bars
Bus-Bar Poten. Trans.
Power factor Indicator
Ammeter
Voltmeter
High-Tension Switch
Tripping Coil
Syn. Plugs
Syn. Lamps
Overload Relay
Syn. Plug Rec.
Potential Transform
Syn. Bus
Taps
Step-down Transformers
Reactance Coils
Starting Switch
To other A.C. Panel
Negative Main Switch
Equalizer Switch
Series-Shunt Switch
Field Break-up Switch
Equalizing Bus.
Negative Bus-Bar

be fully closed, thus connecting the shunt field across the terminals of armature *8* and allowing the field to remain excited even if switches *11*, *11'*, and *15* are open. The transfer switch *s* is provided so that the starting rheostat *S* can be connected to either converter. As soon as switch *11'* is closed, converter *8* should take its share of the load.

33. If the load on converter *8'*, Fig. 16, is heavy or variable, it may be difficult to synchronize converter *8* on account of low or unsteady voltage. In such a case, the speed of *8* may be brought to a little above synchronism, switch *11* opened, switch *m* turned to the right, and switch *4* closed immediately; the machine will pull into step, and its shunt field may be switched on as described in the preceding article. Switch *11* should then be closed and the voltage of *8* adjusted, after which switch *11'* may be closed, thus completing the connections to the bus-bars.

34. In Fig. 17 is shown another scheme of connections for a substation containing two compound-wound rotary converters. The switchboard contains two panels for high-tension alternating current, one panel for each converter, and as many feeder panels as may be necessary. However, connections for only one high-tension panel are shown. This arrangement of connections is used by the General Electric Company, and the direct-current ammeters are of the Thomson astatic type. The series field of each converter is provided with a shunt to regulate the amount of compounding; when starting a converter, its series shunt can be cut out by means of a switch in order to prevent the alternating electromotive force induced in the series coils from setting up a large current through the circuit consisting of the series field and its shunt.

The parts are so named on the diagram that little explanation is needed for most of them. The converters may be started either from the alternating-current end or from the direct-current end. Each converter is equipped with a field break-up switch, which is used when starting from the alternating end. The step-down transformers are provided with


c
T
S
S
b
m

a number of taps, to adapt them to different line voltages. Between the secondary and the converter in each case are the reactance coils (see Art. **13**) and a double-throw starting switch. When the starting switch is in the lower contacts for starting purposes only half voltage is applied to the collector rings, but when the switch is in the upper contacts full voltage is applied for running. The negative and equalizing bus-bars are placed under the floor, and the switches leading to them are mounted on pedestals near the converters, so that there is only one bus-bar back of the direct-current panels and single-pole switches on the fronts.

The diagrams shown in Figs. 16 and 17 give a general idea of the connections used for substations, but such connections admit of considerable variation and must be adapted to the requirements of each particular case.

PORTABLE SUBSTATIONS

35. On large railway systems, even though the distribution system was originally designed of ample proportions to meet all normal conditions, events are likely to occur that attract unusual travel in certain directions at irregular intervals. A special attraction at any point may necessitate running, for a short period, many cars on a branch that ordinarily handles but two or three. The system must be prepared to meet these extra demands; but the installation of sufficient capacity in feeders and substations necessitates an investment that, during a large portion of the time, yields no return. In order to meet these temporarily heavy demands with the least expense, a certain flexibility of distributing system is demanded, so that the increased capacity may be easily and quickly moved from one line to another as the conditions may demand. On a number of systems this flexibility has been attained by the use of **portable substations.** Practically the same apparatus as is used in a permanent substation is assembled in a specially arranged car having very much the appearance of an ordinary freight car. This car can be hauled to any place to which the

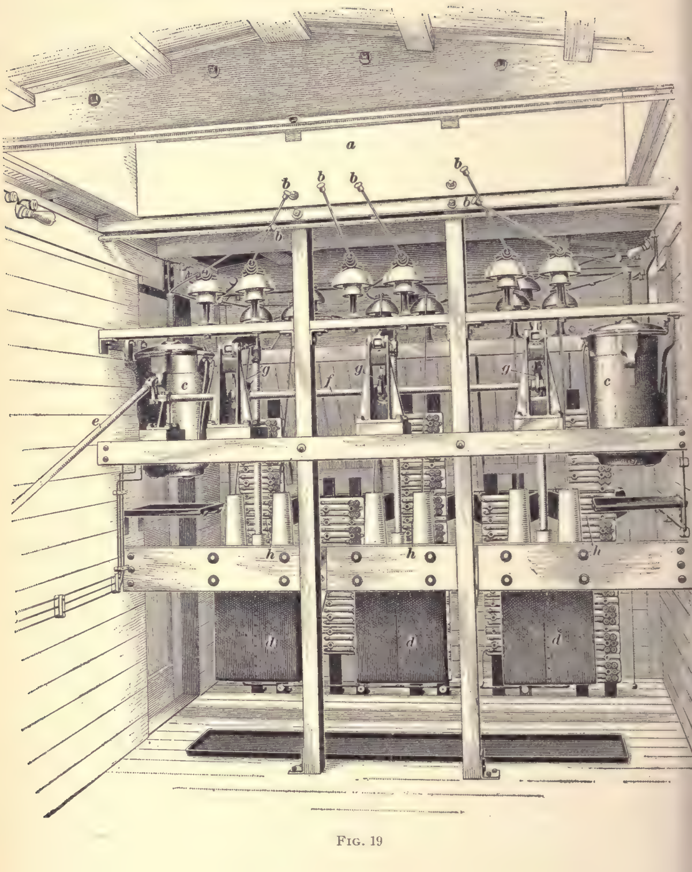


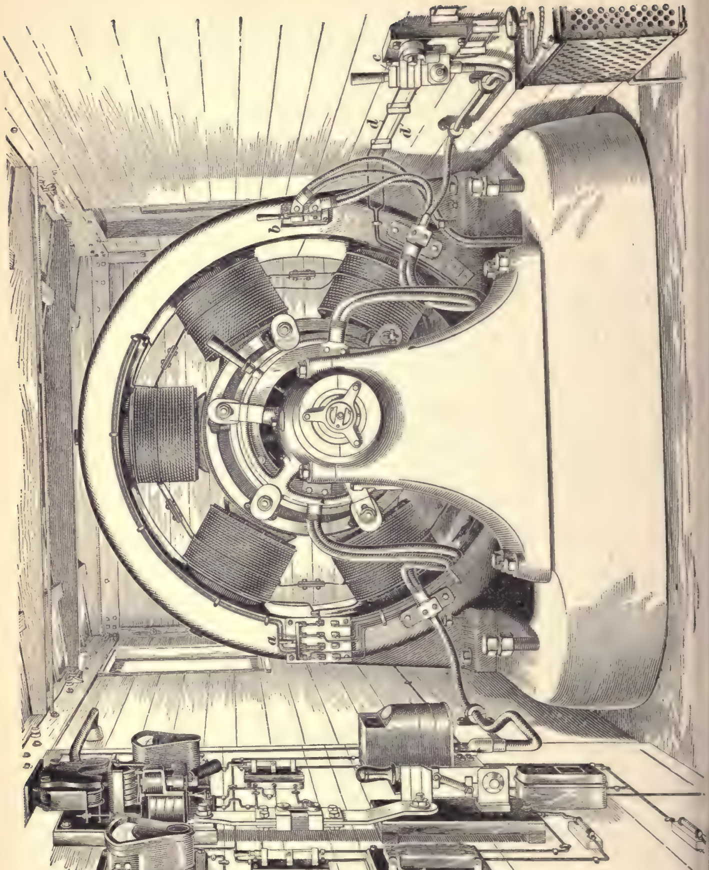
FIG. 19

high-tension lines have been extended, run on a siding, connected up, and put into service in a very short time.

36. In Fig. 18 is shown a view of one end of the interior of a portable substation of 400 kilowatts capacity, built by the General Electric Company for the Cincinnati and Columbus Traction Company. The primary side of the three-phase 25-cycle air-cooled transformers T may be connected for either 33,000 or for 16,500 volts, while the secondary delivers 370 volts. The alternating-current switchboard contains one panel for the high-tension oil-switch operating lever s and one for the double-pole double-throw switch s' for starting the converter. No other provision is made for starting, and no synchronizing devices are necessary. The blower b, with its operating motor m, furnishes the air blast for cooling the transformer. An ammeter c mounted on the side of the car indicates the incoming high-tension line current in one phase.

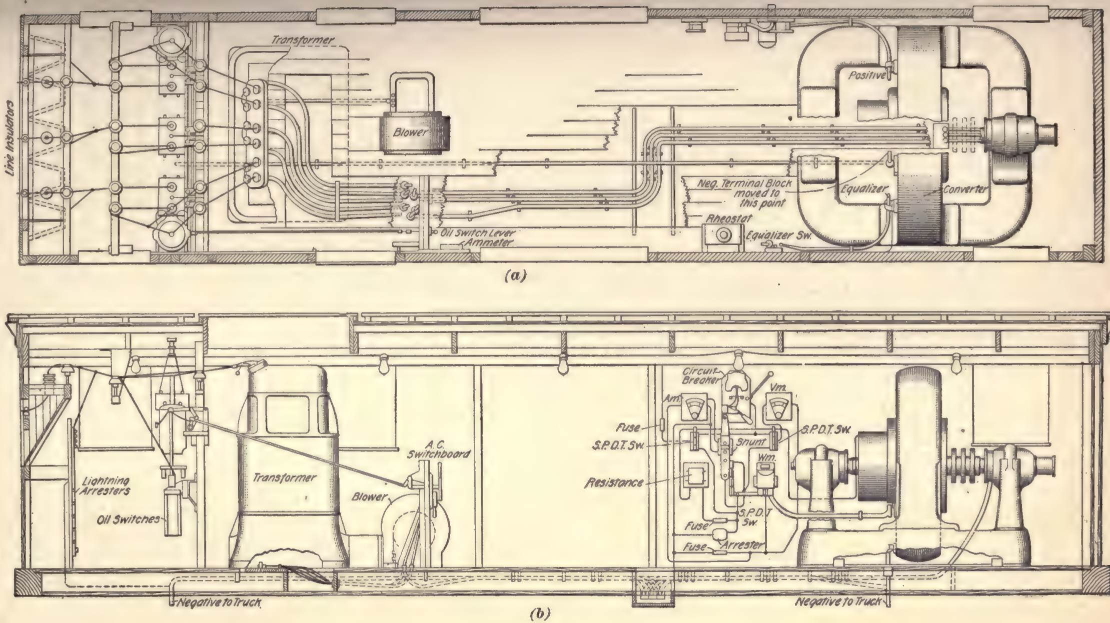
Fig. 19 shows a view of the same end of the car with the transformer removed. A hole a is provided in the roof of the car, through which the transformer is lowered by means of a crane. Terminals b are for connection to the terminal board on the transformer when it is in place. Current transformers c reduce the current for the measuring instruments and the trip coil of the high-tension switch. Oil switches d are operated from the high-tension panel near the transformer by means of connecting-rod e, rod f, and a system of links and levers shown at g. The lightning arresters are shown at h, back of the oil switches.

Fig. 20 shows the 400-kilowatt compound-wound rotary converter in the opposite end of the car. On the left-hand side of the frame is the field break-up switch a, and on the right is switch b for opening the series shunt when starting. An equalizer switch c is installed on the side of the car, so that in case it is desired to operate near other converters, equalizing connections can easily and quickly be made. No negative switch is provided, the negative machine terminal being connected directly to the metal truck, which connects through the wheels with the rails. Wires d, d lead to field



32

33*



Line Insulators
Transformer
Blower
Positive
Neg. Terminal Block moved to this point
Equalizer
Converter
Rheostat
Equalizer Sw.
Oil Switch Lever
Ammeter
(a)
Circuit-Breaker
Vm.
Am.
Fuse
S.P.D.T. Sw.
Shunt
S.P.D.T. Sw.
Wm.
Resistance
S.P.D.T. Sw.
Fuse
Arrester
Fuse
A.C. Switchboard
Lightning Arresters
Transformer
Blower
Oil Switches
Negative to Truck
Negative to Truck
(b)

FIG. 21

rheostat *e*. The direct-current switchboard devices are mounted on slate bases, which are attached to the side of the car near the machine. A flexible cable is taken out through the wall of the car near the circuit-breaker to a terminal block outside, from which connections can be made to the trolley or to one of its feeders, or to the positive bus-bar in a neighboring permanent substation. The converter end of the car is removable, so that the machine is easily installed.

In Fig. 21 (*a*) and (*b*) is shown a plan and elevation that illustrate the general arrangement of the machinery and apparatus, as well as most of the connections. The elevation (*b*) shows the method of bringing the high-tension lines into the end of the car, as well as connections to lightning arresters, oil switches, transformer, etc. The plan view (*a*) shows five secondary cables leading from the transformer to the switchboard near the blower. Two of these cables are for starting purposes only, and hence run only to the starting switch; three cables carry current to the converter. All wiring from the transformer to the converter is carried under the floor of the car.

STORAGE BATTERIES

37. Storage batteries or **accumulators,** are still far from being perfect or fully satisfactory. Some of the disadvantages are their great weight per unit output, high cost, heavy depreciation, necessary care, disagreeable fumes, moisture, etc. In spite of the objections, however, there are many cases where the use of storage batteries in connection with electric-railway stations is found to be a source of economy.

A railway generating station or substation is always subjected to varying demands for current. The variations are of two classes: those which pass through approximately the same cycle of values every day, and those of irregular momentary occurrence, more correctly called *fluctuations*, due to starting cars or heavy grades.

BATTERY TO TAKE PEAK OF LOAD

38. On all electric-railway systems the demand for current is usually least from midnight to about 5:30 or 6 A. M.; from then there is increased demand until about 9:30 A. M., and perhaps another slight increase from 12 to 2 P. M., but the maximum load comes usually from about 5 to 6 P. M., after which it again falls off gradually to the minimum. The station must be prepared to meet the maximum demand, and if sufficient generator capacity is installed, some of the machines must stand idle a good part of the time while the demand is light or else run at low efficiency on greatly decreased load.

One of the most valuable characteristics of storage batteries is their ability to deliver very heavy currents for short periods. The batteries can be charged during periods of light load, and drawn on to help the generators during periods of heavy load. This method not only enables the station to operate with less generating capacity, but permits more efficient operation of the machinery that is installed, because a larger portion of it can be run continuously at, or near, full load. The most economical condition for the operation of a station would be that in which an average load is generated 24 hours per day. This condition would require the installation of the least possible capacity in generators and prime movers, and all the machines could be operated at their maximum efficiency all the time. The use of storage batteries permits an approach toward this condition.

39. In Fig. 22, the irregular line bounding the shaded portion is a **load line,** or **load curve,** showing graphically the variation in the total current supplied by a station during a certain day. The lowest point, about 85 amperes, is reached between 3 and 4 o'clock in the morning; then, the current rises abruptly at 6 o'clock and continues to increase until 9, falling again toward noon, and attaining its maximum value, 2,700 amperes, at 6 in the evening, whence it falls

rapidly and continuously. The heavy loads occurring about 9 A. M. and about 6 P. M. are termed **peaks of load.** To operate such a road, a plant would have to be provided with generators capable of furnishing 2,700 amperes to the line, and probably more on some occasions; but this amount is required during only a short period, and some of the plant would remain idle or work inefficiently for a greater part of the 24 hours. The average current is about 1,276 amperes, and a line a, b drawn through this point indicates the current

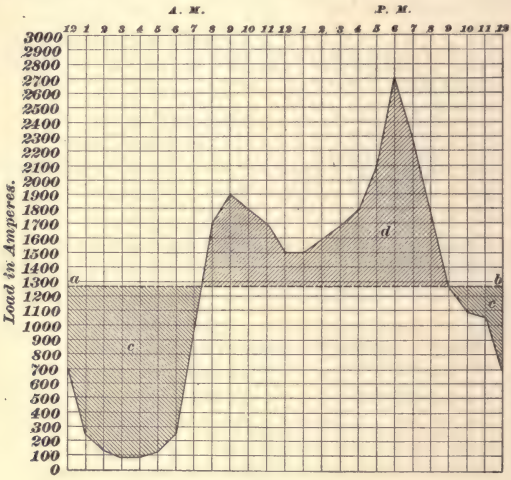


FIG. 22

output if the load were steady all day and of the same total amount. It would be an advantage, then, if the high parts of the load could be brought down and the low parts brought up, and an equalization of the load thus effected. If a storage battery of sufficient capacity were installed in such a station, the dynamos would be called on to deliver only about one-half of the maximum current—1,300 amperes instead of 2,700 amperes—and would therefore have to be

but one-half the size; the engines and boilers could also be correspondingly smaller. The shaded portion marked *c* represents the charge that would be given to the accumulators and *d* represents the discharge. The diagram represents an ideal condition; in actual practice it would be almost impossible to bring the load on the generators down to a straight line like *a b*, but the load could be made so uniform that smaller generators and engines could be used, and the station could be operated at a high efficiency during the greater part of the 24 hours.

40. Fig. 23 is a diagram of actual conditions found in one railway plant in which storage batteries are used. The

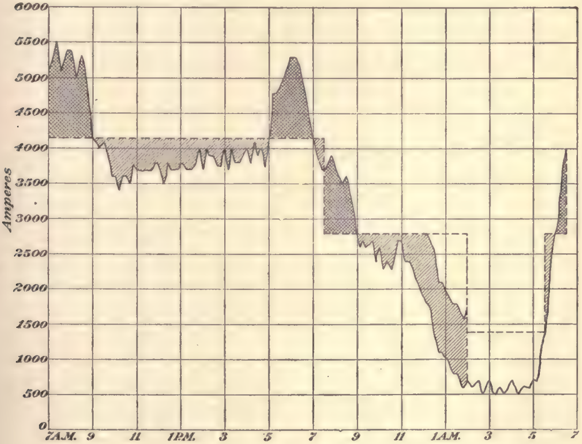


FIG. 23

irregular full line is the load curve. The darker shaded portions represent periods during which the battery is discharging into the line, and the lighter portions periods during which the battery is being charged. From 7 A. M. to 7:20 P. M., the load on the generators is kept practically constant at 4,150 amperes, the battery carrying the surplus, or

peaks of load, above this amount and receiving the difference between the line load and the generator load when the line required less than 4,150 amperes. Thus, the battery was discharging from about 7 to 9 A. M., it received current from the generators from 9 A. M. to 5 P. M., and discharged again from 5 to 7 P. M. At about 7:20 P. M. the generator load was reduced to 2,800 amperes, one generator being shut down; the battery helped supply the line load until 9 P. M. and received the surplus capacity of the two generators above the line load from them until midnight, when it was necessary to reduce the output of the generators in order to prevent too rapid charge of the batteries. Soon after 1 A. M., the battery, being fully charged, was cut out and another generator was shut down, the one remaining machine carrying about 600 to 700 amperes or a trifle less than half load until 5:30 A. M., when a second generator was started and the battery again connected.

STORAGE-BATTERY BOOSTER CONNECTIONS

41. Railway generators and rotary converters are usually compound wound, the series winding being adjusted to increase the voltage as the load increases, or at least to maintain nearly a constant voltage. The electromotive force of storage batteries drops as their load increases; hence, in order to make the batteries discharge into a heavily loaded line, there must be a provision for increasing or boosting their voltage.

Fig. 24 shows connections for a **compound-wound booster.** *A* represents the armature of the generator or converter supplying the circuit; *B*, the armature of the booster, the driving power of which is not represented in the figure; *C*, the battery; *l* and *m*, ammeters; and *R*, a reversing shunt-field rheostat. The shunt field of the booster is connected directly across the circuit, and may be reversed if desired by means of rheostat *R*. The series field carries only the current passing through the battery; this current may flow in either direction. When the battery is connected

to the line, that is, floating on the line, and normal line load is flowing, the booster fields are so adjusted that the combined voltage of the battery and the booster equals the line voltage. In this case, the voltages are so balanced that no current flows through the battery. The series field of the generator *A* must either be cut out or so adjusted that when a heavy load comes on, the voltage of the machine will drop slightly. This drop allows the battery to discharge into the line, and the booster series field is adjusted to hold up, or perhaps slightly increase, the voltage of the battery circuit, so that the battery carries practically all the

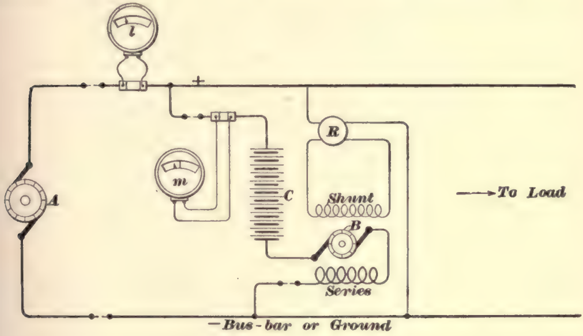


FIG. 24

line load in excess of full generator load. This method does not permit an increase of line voltage with increased load, and hence would be objectionable on suburban or interurban lines, because if a large current were demanded at some point remote from the station, the line drop might be so great as to require for compensation a rise in the station voltage.

42. The **differential booster** was described in connection with *Electric Transmission*. Fig. 25 shows a diagram of connections sometimes used for railway work. The generator armature, the booster armature, the battery, the shunt-field rheostat, and the ammeters are lettered the same

as in Fig. 24. The parts lettered a, b, c, c', and d, Fig. 25, are single-pole switches, c, c' being double throw so that the battery can be connected directly across the line or in series with the booster. The series coils of the booster are in two sections; E carries only the generator current, while D carries the line current; E furnishes practically a constant excitation, and D an excitation that varies with the load. By means of an adjustable shunt (not shown) across the series terminals and by the shunt-field rheostat R, the fields are adjusted so that when normal load is delivered the effects of the magnetizing coils neutralize each other, the booster electromotive force is zero, and the battery voltage equals the line voltage. If the load increases, the effect of D is

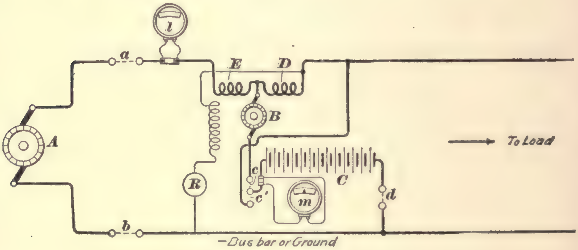


FIG. 25

increased, causing the booster to generate an electromotive force in the same direction as the battery, and the combined voltage of the booster and the battery is great enough so that the battery feeds into the line, thus carrying some or all of the excess load. If the line load falls below normal, the effect of the shunt field predominates and the booster generates an electromotive force opposing that of the battery, which then receives current from the generator. During periods of light load, it is sometimes necessary to charge up a battery when operating in this way, as the intermittent charging it receives during regular operation is not sufficient.

Frequently, the connections of a differential booster are varied somewhat from those shown in Fig. 25; for example,

there may be several shunts of different values across the terminals of the series field with switches arranged to cut any of them into circuit or, perhaps, to cut the series field

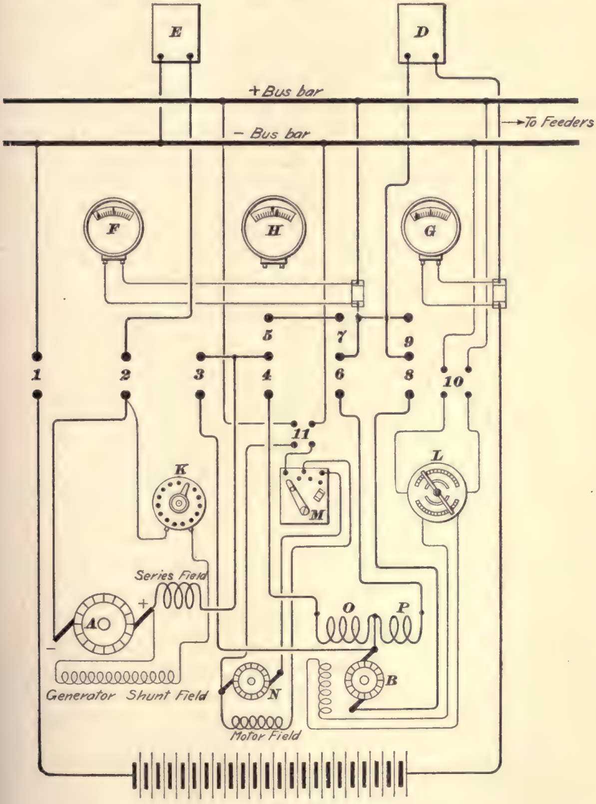


FIG. 26

entirely out of circuit and operate the booster as a shunt machine. This would be done if the load on the line were

fairly steady, the necessary regulation then being secured by manipulating the field rheostat.

43. Fig. 26 shows a scheme of switchboard connections for a differential booster. *A* is the generator armature, *B* the booster armature, *D* an underload-and-overload battery circuit-breaker, *E* the generator circuit-breaker, *F* the generator ammeter, and *G* the battery ammeter with its zero point in the center of the scale. The voltmeter *H* is so connected to a switch that readings may be taken of the generator voltage, the battery voltage, or the voltage of the battery plus that of the booster; the voltmeter connections have been omitted in order not to make the figure confusing. *K* is the generator-field rheostat, *L* the reversing rheostat for the shunt field of the booster, *M* the starting rheostat for the shunt motor *N*, which drives the booster, and *O P* the series fields of the booster. Switches *1*, *2*, *3* are single-pole single-throw, and *4–5*, *6–7*, *8–9* are single-pole double-throw. Switch *10* connects the shunt field of the booster to the bus-bars, and *11* is the main switch for the motor. The combinations that may be affected are as follows:

1. Generator working alone on bus-bars with battery and booster cut out of service: Switch *2* is closed, and switches *5* and *7* thrown to the upper position; all other switches are open.

2. Battery working alone on bus-bars, generator and booster cut out of service: Switch *1* is closed, and switch *9* thrown to the upper position; all other switches are open.

3. Battery and generator operating in parallel on bus-bars with booster in service: Switches *1* and *2* are closed, and switches *4*, *6*, and *8* thrown to the lower position; switches *10* and *11* are also closed because the booster is now in operation.

4. Battery in parallel with generator, series coils of booster cut out; in this case *B* is operated as a shunt-wound booster and the battery is being charged: Switches *1*, *2*, and *3* are closed; switch *8* is thrown to the lower position and switches *5* and *7* to the upper position; switches *10* and *11*

are also closed, and L is adjusted so that the booster helps the battery to charge.

44. Carbon Regulator.—In Fig. 27 is shown a diagram of connections of a carbon regulator manufactured by the Electric Storage Battery Company. The booster has but one field winding, which is energized by a small dynamo called an *exciter*. Both the booster and the exciter are driven at a constant speed. The regulator consists of a lever AB pivoted at a point p between piles of carbon disks k, l. Suspended from one end of the lever is the soft-iron core of a solenoid C that carries the total generator load. The other end of the lever is held by a spring s capable of adjustment by the hand wheel r. The field ad of the exciter is connected to a point b at the middle of the battery and to a point c between the two sets of carbon piles. If the load on the generators increases beyond the amount for which the regulator is set, the carbon piles k are compressed as shown in the diagram, thus greatly decreasing the resistance through them. At the same time, the pressure on piles l is decreased and the resistance through them increased. The path of the current through the exciter field is then from b through d–a–c–k and back to f. If the generator load falls below normal, the spring draws end B of the lever downwards, carbon piles l are compressed, and piles k are released, thus decreasing the resistance of the one and increasing that of the other. The current through the exciter field will then flow from e through l–c–a–d and back to b. The strength of the exciter field current may, therefore, be changed from a maximum in one direction to zero

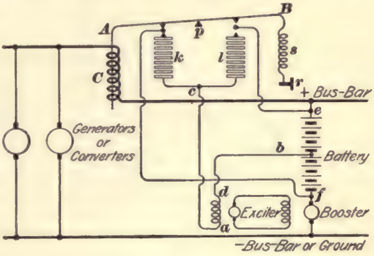


FIG. 27

and to a maximum in the other direction, all by the varying pull on A, due to varying current through the solenoid C.

Fig. 28 shows the complete carbon regulator; a is a metal cylinder incasing the coiled spring, b the piles of carbon disks, c the solenoid composed of copper strip, and d the core on which the pull varies according to the current flowing through the solenoid. This regulator is very sensitive and is capable of close adjustment; by its use, the booster electromotive force may be automatically increased, decreased, or reversed, according to the requirements of the system. The

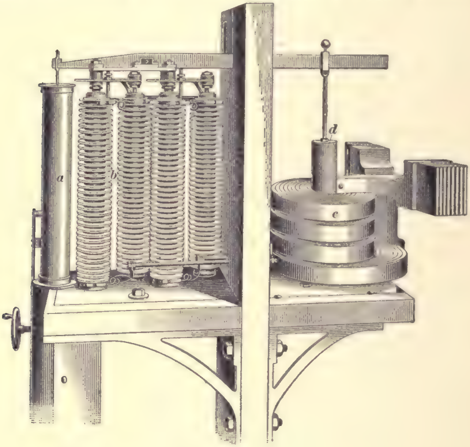


Fig. 28

battery may be made to supply all the line load in excess of full generator load, or, if the excess is greater than the battery can supply with safety, the regulator may be so adjusted that a portion of the overload will automatically come on the generators. On the other hand, if the load on the generators becomes so small that the batteries might receive too great a charging current, the regulator can be set to limit this current to a certain maximum. These limits in either direction are affected by limiting the motion of the lever arm.

45. Counter Electromotive Force System.—Fig. 29 shows a diagram of connections used by the Gould Storage Battery Company and known as the **counter electromotive force system.** *G* is the main generator, or rotary converter. The return current from the rails flows through the field coil *S* of a small generator *g* known as the counter electromotive force generator. The generator *g* and the booster *B* are both driven at a constant speed by a driving power not represented in the figure. Across the terminals of the field coil *S* may be one or more shunts *s*, each with a switch, so that the current through the coils may be adjusted to suit the requirements. The adjustments are made so that when a certain current, say, the full-load current of the generator, is returning from the rails, the voltage of *g* equals the line

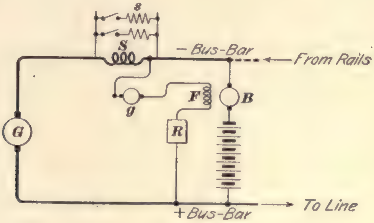


FIG. 29

voltage. If the generator load increases, the voltage of *g* exceeds that of the line, the excess being used to force current through the booster field *F* in a direction to cause the battery to discharge. If the generator load decreases, the voltage of *g* will be less than the line voltage; this deficiency causes current to flow from the line through the booster field in a direction to cause battery charge. The electromotive force across the booster-field terminals thus varies from a certain maximum in one direction to zero, and to a maximum in the opposite direction according to the value of the generator current. The booster *B* may thus assist the battery to feed into the line, or it may remain inactive, or it may assist the line voltage to charge the battery according as

the line load exceeds, equals, or is less than the capacity of the generator.

A field rheostat R serves to regulate the current through the booster field F and thereby to adjust the amount of load variation on the main generator G. For example, if the current through the booster field is small, the magnetic circuit of the booster is below saturation, and a very little change in the field current produces a considerable change in the booster voltage; but if the booster-field current is high, causing a high state of magnetic saturation, much greater change in the field current is necessary to produce the same change in the booster voltage. From this it is evident that if the booster-field current is low, the load on the main generator can change only a little before the booster voltage will be affected enough so that the battery will help the generator G when the line load is high, or absorb current from the generator when the line load is low. But if the booster-field current is high, a considerable change in the load on the main generator is necessary before the booster voltage will be much affected.

STORAGE BATTERY AS A REGULATOR

46. The discussion of storage batteries thus far has been with regard to the periods of charge and discharge lasting for some little time. In railway work, especially in small or medium-sized plants, there are sudden and severe changes or fluctuations, of load, due to grades and to starting and stopping cars. These sudden changes are a severe trial to the generators and engines or to the converters, and are likely to cause severe sparking and extreme variations of voltage. Storage batteries are sometimes installed purposely to smooth out these fluctuations. If the batteries are required for this purpose alone, they may properly be called *regulator* or *equalizer batteries*. They act in a capacity similar to that of a heavy flywheel on an engine that is not required to produce the same torque during all portions of a revolution. The name "buffer-batteries" is also sometimes applied to batteries used for regulating purposes.

47. Batteries used only for regulating purposes do not require as much capacity as those used for storage for longer periods. The charging and discharging currents, lasting for a few seconds only, may be much larger than if they were to continue for possibly 2 or 3 hours. As a matter of fact, batteries intended to absorb energy during the night and a portion of the midday and return it to the system during the morning and evening load periods, are nearly always left floating on the line, so as to care for the fluctuations.

In an equalizer battery the conditions at one portion of the day may be as shown in Fig. 30, which represents the

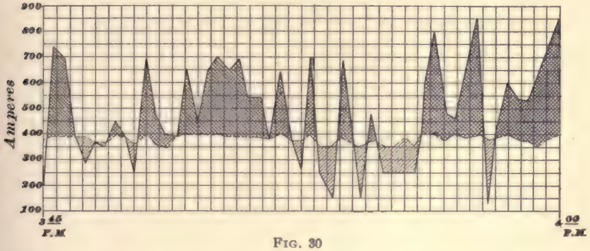
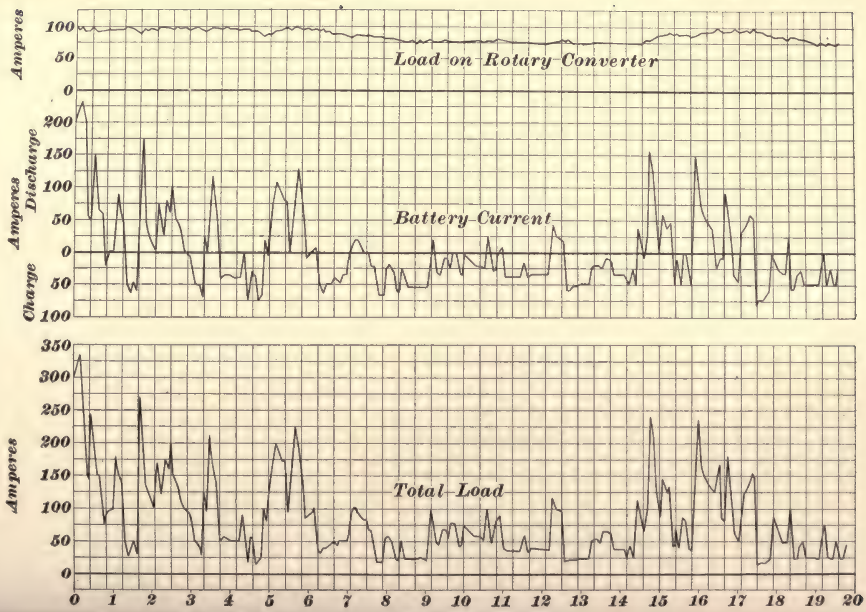


Fig. 30

current output from a street-railway station equipped with a battery of 258 chloride cells. The irregular boundary line of the shaded portion shows the station output, which, within 15 minutes, varies from a minimum of less than 150 amperes to a maximum of over 840 amperes, thus showing that the fluctuations are very sudden and severe. In spite of these fluctuations, the load on the dynamos is kept within 350 and 400 amperes, as shown by the dotted line, the double-sectioned areas above this line representing the discharge intervals, and the single-sectioned areas below the line, the charge intervals. The ampere-hours discharge during the 15 minutes represented is considerably greater than the charge, as is indicated by the greater area of the double-sectioned portion of the figure; but if the load curve were drawn for a longer period, say 24 hours, the charge would likely be in excess of the discharge.


Amperes
100
50
0
Load on Rotary Converter
Amperes
Discharge
200
150
100
50
0
Charge
50
100
Battery Current
Amperes
350
300
250
200
150
100
50
0
Total Load
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

The curves in Fig. 31 are taken from a street-railway substation from which current is supplied from a rotary converter used in conjunction with a storage battery to take up the load fluctuations. In this case, the charge and discharge areas of the battery curve are more nearly equal than in Fig. 30. The loads on the converter and the battery are plotted separately in Fig. 31; the lowest curve represents the total output of the substation, and is obtained by adding the battery discharge current to the converter current and subtracting the battery charging current from the converter current. During the 20 minutes represented by the curve, the total load varied from below 25 to over 325 amperes, but the converter supplied practically a steady load of 75 to 100 amperes, the battery caring for all the fluctuations; this resulted in a steady load on the main station supplying the converter.

48. Most of the booster-regulating devices already described are applicable to batteries floating on the line. The regulating device must be such that an increased line current will cause a prompt increase of booster voltage in the same direction as the battery voltage, so that the sum of the two will slightly exceed the electromotive force of the generator or converter. A diminished line current, on the other hand, must just as promptly result in a booster electromotive force opposing that of the battery so that current flows back through the battery, thus charging it.

BATTERY OUT ON THE LINE

49. On long railway lines where a considerable load is required at a distance from the power house or substation, it is sometimes a source of economy to install storage batteries out on the line. The least possible loss in transmission lines occurs when the flow of energy over them is at a continuous, uniform value. If one or more cars are operating near the end of a long trolley line, the flow of energy in the feeders to that section may be considerable, and it

will fluctuate in value as the cars start and stop; at another time in the day all the cars may be near the power station, so that no energy is flowing over the larger portion of the line.

The effect of a fluctuating load in increasing the loss in a transmission line may be illustrated by an example: Suppose that 55,000 watt-hours are required within a period of 2 hours at a point some distance from the station and that the resistance of the circuit to and from the point is .1 ohm. If the pressure is 500 volts, 100 amperes for 1 hour followed by 10 amperes for 1 hour will transmit the required amount, or, instead of this, a constant current of 55 amperes for 2 hours will do it. In each case, the loss in watt-hours may be found by multiplying the square of the current by the resistance of the circuit and by the time in hours. In the first case, the loss would be $100 \times 100 \times .1 \times 1 + 10 \times 10 \times .1 \times 1 = 1{,}010$ watt-hours, and in the second case $55 \times 55 \times .1 \times 2 = 605$ watt-hours; that is, 405 watt-hours less in the second case than in the first. The difference is due to the predominating influence of the squares of the higher current values, and the more extreme the fluctuations, the greater the excess loss.

The voltage at the end of a long line fluctuates widely, dropping, due to line drop, whenever there is a heavy flow of current to that end and rising again to the same value, as at the station bus-bars, when no current is flowing. Storage batteries at such a place are self-regulating. If cars are operating near the end of the line, the voltage can drop no lower than that of the battery, for if it does, the battery feeds into the line and less current is then drawn from the station. When no cars are in that vicinity, the line voltage rises above that of the battery, which then receives a charging current. The energy flowing over the line is thus kept fairly constant, and for a given line loss, less feeder copper is required than if the batteries were not used.

50. An example of the practice just mentioned is found in the installation of the South Side Elevated Railroad

of Chicago. The line is long, the cars are heavy and operated in trains, and the acceleration is rapid, so that, without the regulating battery, the flow of current to the end of the line, when a train is at that place, would be very large and the stress on the feeders severe. The power station is near the center of the line, and a storage battery floats across the line near each end. The line drop varies from 10 to 30 volts, according to the load; the battery absorbs energy when the drop is least and discharges into the line when the drop is greatest.

51. The automatic regulation of such a battery requires that there be a certain variation in drop. If it is found that the battery is discharging too much, the remedy is to remove a few cells or to reduce the line drop by installing greater feeder capacity; if the battery is receiving more charge than is necessary, more cells or less feeder capacity and greater line drop from the station is needed. Instead of changing the feeder capacity to regulate the amount of charge and discharge, it may be desirable to regulate by using a few more or a few less cells in series in the battery; this raises or lowers the battery voltage and consequently the voltage at which the cars must operate.

In case of extensions to a system or of increased traffic at a distance from the station, when additional feeders would seem to be necessary, it may be found that the feeders already installed will be sufficient if a storage battery is used near the point of increased demand, and possibly the battery will be the more economical. This will depend very much on the conditions; if the increased demand comes only at intervals, the battery will doubtless be the most economical and satisfactory, but if the increased current must be fairly constant, the reverse may be true.

52. At a distance of $2\frac{1}{2}$ miles from its power station, a Chicago elevated railroad company has installed a storage-battery substation containing 258 chloride cells. With this battery is a motor-generator booster set, the booster being compound wound. This substation feeds a section of about

$1\frac{1}{2}$ miles of four-track road, there being two express tracks and two local tracks. The substation was installed after the demand for current in that vicinity became too great to be supplied economically from the power station. It is expected that the station will be capable of supplying a still greater future demand in its section and beyond. The battery is rated at a maximum discharge rate of 2,720 amperes for 1 hour, a normal discharge rate of 680 amperes, a maximum charge rate of 950 amperes, and a normal charge rate of 680 amperes. The circuit-breaker, however, is set for a maximum discharge of 4,080 amperes, so that the battery can supply infrequent momentary excess demands. The battery is not left to operate automatically all the time, although it practically does so for certain periods. It is charged at regular intervals by connecting to the express-track feeders at times when express trains are not running. On Sunday mornings, the battery is given an "overcharge;" that is, it is charged as fully as possible, after which all the cells are carefully inspected and each compared with the others. If a cell shows lack of gassing, a drop in specific gravity, low voltage, markedly lighter positives or markedly whiter or darker negatives than its neighbors, short circuits or other troubles are suspected and the cause must be found and removed.

53. Selection of a Battery.—In order to select a battery for a given service, it is first necessary to determine as nearly as possible the load line on which the battery is to operate. By measuring the probable battery-discharge areas on such a line the capacity in ampere-hours can be told very closely. It is the usual practice to install more jar or tank capacity than is needed at once, so that the battery capacity can be increased as the system grows, by adding more pairs of plates. The number of cells to be connected in series will depend on the voltage required as well as on the extent to which it is desirable to have the cells discharge. In the substation described in the preceding article, the instructions are that the battery voltage must never fall below 440 when

the discharge rate is 680 amperes. If the rate of discharge is less, the voltage must be higher. The number of cells connected in parallel, or the area of plate surface in parallel, will depend on the construction of the plate and the required rate of discharge.

INTERIOR WIRING

(PART 1)

PRELIMINARY CONSIDERATIONS

1. The subject of interior wiring involves a study of the various methods for supplying electric current to devices, such as lamps, motors, etc., used in buildings; also, the methods for operating bells, burglar alarms, and other minor appliances operated by electricity.

In electric wiring, the ultimate object is the conveying of the electricity to the lamp, bell, motor, or other device that is to be operated. But this must be done in a proper manner; otherwise danger, unsatisfactory operation, and waste are sure to result.

2. Four things should be considered in every electric installation: (*a*) safety, (*b*) satisfactory operation, (*c*) convenience and neatness, and (*d*) economy. The first is by far the most important. Therefore, the electrical worker should understand, first of all, what are the sources of danger in the use of electric currents and then what precautions are necessary and what conditions must be complied with to avoid these dangers. When he thoroughly understands these things, he should learn how to make his work satisfactory in other respects and profitable to himself.

The same causes that, under certain conditions, make electricity dangerous to life also make it a source of fire hazard. There are also conditions under which an electric current may cause fire, although it may not be directly

dangerous to life. In discussing the precautions necessary to avoid any chance of fire from an electrical cause, the student will learn how to avoid danger to life as well, so that it is unnecessary to discuss that subject by itself.

FIRES CAUSED BY ELECTRIC WIRING

3. The so-called "electrical fires," or fires that are caused by the presence of electric wires or apparatus within a building, can be divided into three classes, as follows:

1. Fires caused by poor work or improper materials.
2. Fires caused by overloading the apparatus or wire with a higher voltage or with more current than it was designed to carry.
3. Fires caused by lightning striking the outside lines or by the crossing of circuits that should never come into contact with one another.

A good job of interior wiring overcomes all danger due to the first two of these sources of hazard and most of the danger due to the third, but not all, for accidents sometimes occur outside of the buildings, against the results of which the present accepted devices for the protection of inside circuits are not sufficient. The failure of a lighting company to use proper lightning arresters and transformers or to insulate the outside wires thoroughly may cause trouble within a building in which the wiring is properly done.

THE NATIONAL ELECTRICAL CODE

4. When electric lights first came into general use, the insurance companies discovered that there were many fires of electrical origin, because the wiring was of very inferior workmanship. The various associations of underwriters, therefore, formulated rules in accordance with which they required that all wiring be done or they would not insure buildings containing it. In the course of time, these various rules of local associations were reduced to a uniform code, and finally, in 1898, they became known as the **National Electrical Code** and received the indorsement of practically

all the inspection bureaus throughout the United States, besides that of the following organizations: the American Institute of Architects, the American Institute of Electrical Engineers, the American Society of Mechanical Engineers, the American Street Railway Association, the Factory Mutual Fire Insurance Companies, the National Association of Fire Engineers, the National Board of Fire Underwriters, the National Electric Light Association, the Underwriters' National Electric Association.

A few cities have rules of their own that differ slightly from this code, but the differences are not vital. Any person doing work in any city where there is municipal legislation governing his work should investigate the laws of that particular place before undertaking to lay out work for himself. Every wireman should be supplied with a copy of the latest edition of the National Electrical Code and do work in compliance with those rules, whether additional laws exist or not. Copies of the code and of all other information published by the Underwriters' Association for the sake of reducing the fire hazard can be obtained by writing to the laboratories of the National Board of Fire Underwriters at Chicago or by applying at the nearest Underwriters' Inspection Bureau. The rules are revised by conventions as often as changes in the electrical art make such revision necessary.

5. Fittings That May Be Used.—In addition to this code of rules, the National Board of Underwriters publishes twice each year a **list of approved fittings** for use in connection with the code. This list contains the names of articles that have been found entirely satisfactory, together with the names of the manufacturers. It does not contain a list of *all* fittings that will pass inspection, and many good articles are not listed in its pages.

EXAMPLES OF ELECTRICAL FIRES

6. That the student may properly understand the nature of the fire hazard due to the presence of electric circuits, before studying the various preventives, the following typical examples of electrical fires are briefly described. These are reports

of actual fires and burn-outs taken from the Quarterly Fire Reports of the National Board of Fire Underwriters.

1. Loose connection on series incandescent circuit in show window. Arc ignited insulating covering of wire and fire spread to surrounding inflammable material. Four sprinkler heads opened and extinguished the fire. Contents of window destroyed.

2. Socket-shell burn-out in show window of millinery store. Short circuit caused by metallic shell of socket on window fixture establishing connection between projecting strands of flexible fixture wire.

3. Paraffin-covered wire used for pendants for drop lights. Wiring installed on a motor circuit, after inspection, by occupant of building who wished to secure light. Short circuit ignited paraffin covering and whole place burned up.

4. Short circuit or ground on constant-potential lighting circuit, where mains ran unprotected through damp woodwork in a brewery. The arc thus formed ignited insulating covering of the wire and fire communicated to woodwork of frame building.

5. Short circuit in flexible cord in show window burned out the window.

6. Heating effect of incandescent lamp. A 16-candle-power incandescent lamp on a 52-volt circuit was left lying on a coat in a newspaper office. About 4 hours after the lights were turned on the coat was discovered smouldering, and on being moved burst into flame.

7. Revolving wheel of incandescent lamps in show window covered with handkerchiefs burned out the window either by sparking at the commutator or from heating effect of the lamps.

8. Sparks from an arc lamp dropped on a table underneath that was covered with open boxes of shirt waists. The table and contents destroyed, otherwise no considerable damage.

9. Flexible lamp cord wound around a gas fixture having a soft-rubber insulating joint. The current grounded through the joint and the arc ignited the escaping gas.

10. Overheating of No. 14 B. & S. wires due to partial short circuit, caused by moisture, through porous crockery knobs on which wires were mounted. The fuses, which were too large, did not melt for some time and the burning insulation of the wires set fire to combustible material near, causing a loss of $15,000.

11. A fuse block, improperly constructed and placed in close proximity to woodwork, held an arc after a short circuit long enough to set fire to the woodwork.

12. Main feed-wires placed in an elevator shaft were short-circuited by a breakdown of their insulation. A heavy arc was established that set fire to building.

13. Overheating of resistance coil of arc lamp that was improperly insulated and too near adjacent woodwork set fire to building.

14. Short circuit of No. 14 wires installed, contrary to rules, in molding in a place exposed to moisture. The fire was stubborn and burned fitfully between floors and was not extinguished before a loss of $2,000 had been sustained.

15. Fire in public institution. Building wired throughout with weather-proof wire run through joists without bushings, both wires of the circuit being brought through one hole at lamp outlet without separation. Short circuit occurred in attic that quickly set fire to dry timbers.

16. An Edison plug cut-out was improperly used to protect a 5-horsepower motor operating at a difference of potential of 220 volts. Fuse in blowing failed to open circuit, thus maintaining an arc that set fire to building.

17. Circuit controlling an electric flat iron was left turned on, becoming overheated and setting fire to the table. Circuit had no signal lamp or other indicating device recommended for such equipment.

18. Overheating of mechanism in a 2,000-candlepower series arc lamp, the metal casing of which did not fit, set fire to the ceiling. The store was closed, but the lamp had been left burning until the circuit was shut off. This fire illustrates the advisability of cutting all current out of buildings when the same are unoccupied.

19. A fire occurred in show window, caused by a bath towel falling from support on to a lighted incandescent lamp in bottom of window; the towel becoming ignited set fire to the contents of window and damaged some of the stock in store.

20. Lightning entered building over badly installed watchman circuit. No protective devices at entrance to building. Wires badly insulated; fastened by staples. Heat of wires set fire to joists of building.

21. Ground of 110-volt circuit on gas pipe in attic. Arc burned $\frac{1}{4}$-inch hole in pipe and set fire to escaping gas.

22. Fire in basement of building caused by accumulation of sodium salt on back of three-wire molding run on brick wall. Trouble occurred at a point where a nail had been driven through molding into wall.

23. Short circuit in fixture canopy ignited ceiling above fixture. Fire also occurred at same moment in cabinet at center of distribution. It was found on inspection that the branch cut-out contained copper wire.

24. An ignorant workman installed a lighting circuit in lead-covered cable, fastening same to iron ceiling with staples. Breakdown of insulation of cable set fire to ceiling, when it was found that no main switch had been installed and current could not, therefore, be cut off.

25. Switch on electric-light circuit was mounted in dry-goods store at a point where draperies came in contact with it. Flash from same ignited draperies and fire spread rapidly to millinery and other inflammable material.

26. Breakdown of insulation on wires of lighting circuit in a fine residence set fire to woodwork inside partitions. Fire occurred at night, and owing to delay in sending in alarm and the distance from fire-department headquarters, fire was not extinguished until a heavy loss had been sustained.

27. Electric-light wire sagged and made contact with telephone wire running to cable box. Box and cable connections completely destroyed.

28. Burglar-alarm, electric-bell, and electric-light wires came together inside the partitions of a residence. The

insulation on the wires was ignited and fire followed up the partitions. Owing probably to lack of oxygen, fire did not break out of partitions, but spread so generally over the house inside that much damage had to be done before it could be extinguished.

29. Circuits were run in circular loom tubing immediately over a steel ceiling. Where the tubing came through the ceiling for a loop, the sharp edges of the ceiling cut through the same, short-circuiting the wires. Arc ignited the insulation of the wires, fire following same up under the ceiling.

30. Fire in livery stable due to blowing of fuse in uncovered cut-out into straw. Fire spread so rapidly that it was impossible for the department to control it.

31. Fire in basement of hotel caused by water leaking and running down the blades of a switch on 500-volt circuit.

32. Serious burn-out of a fire-alarm system by cross on 500-volt feed-wires of an electric railroad. Nine fire-alarm boxes, a tapper, and an indicator were burned out, the repeater also being partially destroyed. Fire was also started in the residence of the chief of the fire department, but was promptly extinguished. It was found on inspection that the instruments were protected by fuses that were much too short.

7. Figs. 1 to 6 illustrate some characteristic burn-outs; they have been drawn from photographs of burn-outs that have actually occurred.

Fig. 1 shows a gas pipe that was melted by an arc caused by a heavy current-carrying circuit crossing a signal circuit that was connected to the pipe. The connection to the pipe was poor and unsoldered.

Fig. 2 shows joints made with No. 10 wire on a circuit designed to carry 200 amperes. The use of such a poor joint gave rise to heating that resulted in the burning out of the wire.

Fig. 3 shows a fixture canopy with a hole melted through it, caused by a fixture cut-out inside the canopy becoming short-circuited.

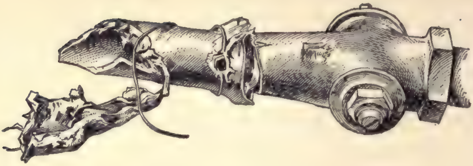


FIG. 1

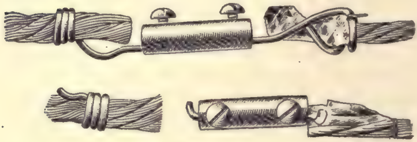


FIG. 2

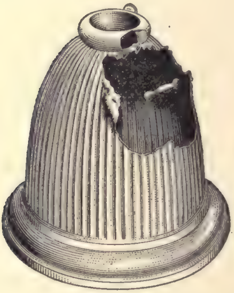


FIG. 3

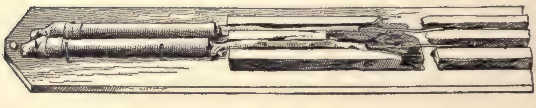


FIG. 4

Fig. 4 shows a burn-out caused by a short circuit between weather-proof wires used in molding. Wire with weather-proof insulation only should never be used in molding, and its use in molding is prohibited by the Underwriters.

Figs. 5 and 6 show burn-outs caused by short circuits in cut-outs. The burn-out in Fig. 5 was due to defective design,

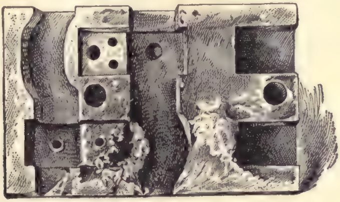


Fig. 5

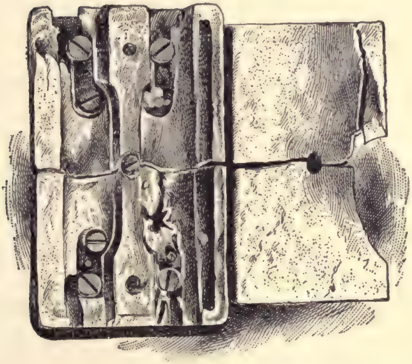


Fig. 6

the two sides of the circuit being brought so close together that when a fuse melted the arc held over and destroyed the cut-out.

In Fig. 6 the cut-out was placed horizontally. When the fuse melted, the metal ran down and established connection between the lines, thus resulting in a short circuit.

GENERAL RULES

8. In wiring for electric lights and power, there are certain rules that apply equally to all systems and voltages; these will be our first study. In what follows, rules and explanatory notes taken from the National Electrical Code are indented in order that they may be distinguished from the explanations and other matter. In most localities these rules have the force of laws. Many of the National Code rules deal with the construction of the various fittings used for interior wiring; these concern the manufacturers of the fittings rather than the workmen who install them. Most of the rules here given relate to the installation of appliances. Fittings given in the lists issued by the National Board of Fire Underwriters comply with their rules.

GENERAL RULES—ALL SYSTEMS AND VOLTAGES

Wires—

> *a.* Must not be of smaller size than No. 14 B. & S., except in fixtures and flexible cords.

This is because wires of smaller size are likely to break or become loose, so that the work does not remain mechanically secure, and because a small wire is much more likely to be overloaded by connecting a few additional lamps to it than is a larger wire.

> *b.* Tie-wires must have an insulation equal to that of the conductors they confine.
>
> *c.* Must be so spliced or joined as to be both mechanically and electrically secure without solder; they must then be soldered to insure preservation, and the joint covered with an insulation equal to that on the conductors.
>
> Stranded wires must be soldered before being fastened under clamps or binding screws, and

whether stranded or solid, when they have a conductivity greater than No. 8 B. & S. gauge, they must be soldered into lugs for all terminal connections.

All joints must be soldered, even if made with some form of patent splicing device. This ruling applies to joints and splices in all classes of wiring covered by these rules.

9. Whenever it is possible to avoid making joints, it is advisable to do so; but where joints are necessary, great care must be taken to do the soldering well, and to leave no corrosive acid on the wire. There are several soldering compounds now on the market that will tin the wire well enough to make a good joint and yet leave no acid on it. Soldering flux in the form of sticks is more convenient than liquid soldering fluid.

FIG. 7

FIG. 8

Soldering Fluid.—

The following formula for soldering fluid is suggested:

Saturated solution of zinc chloride	5 parts
Alcohol	4 parts
Glycerine	1 part

10. **Joints.**—Figs. 7, 8, and 9 illustrate joints in common use. In removing the insulation from the wires where joints or connections are necessary, and in scraping the wire to clean it before making the joint, great care must be exercised not to cut into the wire and lessen its cross-section and consequently, its carrying capacity. Especial care must be taken in handling

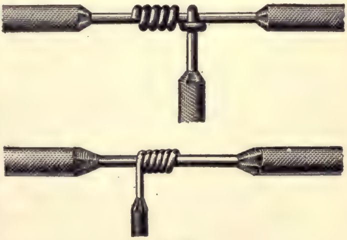


FIG. 9

fixture wires, which are small and easily cut or broken. A comparatively small nick in a copper wire will make it break easily.

In recovering the wire with insulating tape, a sufficient amount of tape must be used to afford ample protection. When rubber-covered wires are spliced or joined, two kinds of tape must be used, the first of pure rubber softened by a volatile oil, and the second of cloth saturated with a moisture-proof adhesive material.

11. Rules Relating to Wires (Continued).—

d. Must be separated from contact with walls, floors, timbers, or partitions through which they may pass by non-combustible, non-absorptive insulating tubes, such as glass or porcelain.

Bushings must be long enough to bush the entire length of the hole in one continuous piece, or else the hole must first be bushed by a continuous waterproof tube. This tube may be a conductor, such as iron pipe, but in that case an insulating bushing must be pushed into each end of it far enough to keep the wire absolutely out of contact with the pipe.

e. Must be kept free from contact with gas, water, or other metallic piping, or any other conductors or conducting material that they may cross, by some continuous and firmly fixed non-conductor, creating a separation of at least 1 inch. Deviations from this rule may sometimes be allowed by special permission.

When one wire crosses another wire, the best and usual means of separating them is by means of a porcelain tube on one of them. The tube should be prevented from moving out of place, either by a cleat at each end or by taping it securely to the wire.

The same method may be adopted where wires pass close to iron pipes, beams, etc., or, where the wires are above the pipes, as is generally the case, ample protection can frequently be secured by supporting the wires with a porcelain cleat placed as nearly above the pipe as possible.

f. Must be so placed in wet places that an air space will be left between conductors and pipes in crossing, and the former must be run in such a way that they cannot come in contact with the pipe accidentally. Wires should be run over, rather

than under, pipes on which moisture is likely to gather or which, by leaking, might cause trouble on a circuit.

g. The installation of electrical conductors in wooden molding or when supported on insulators in elevator shafts will not be approved, but conductors may be installed in such shafts if incased in approved metal conduits.

Underground Conductors—

a. Must be protected, when brought into a building, against moisture and mechanical injury, and all combustible material must be kept removed from the immediate vicinity.

b. Must not be so arranged as to shunt the current through a building around any catch box.

This refers to catch boxes in the street, from which the wires should run to the buildings, and not from street to building, building to building, and back again into the street, around one or more catch boxes, thus shunting whatever protective devices there may be in the catch boxes.

c. Where underground service enters building through tubes, the tubes shall be tightly closed at outlets with asphaltum or other non-conductor, to prevent gases from entering the building through such channels.

d. No underground service from a subway to a building shall supply more than one building except by written permission from the Inspection Department having jurisdiction.

12. Carrying Capacities of Wires.—As every wire carrying an electric current is somewhat heated, it is necessary to know how much current can safely be carried by a wire of a given size. Table I supplies this information.

Table of Carrying Capacity of Wires.—

The accompanying table (Table I), showing the allowable carrying capacity of wires and cables of 98 per cent. conductivity, according to the standard adopted by the American Institute of Electrical

TABLE I

CARRYING CAPACITY OF INSULATED WIRES

B. & S. Gauge	Rubber-Covered Wires Amperes	Weather-Proof Wires Amperes	Circular Mils (Approximate)
18	3	5	1,624
16	6	8	2,583
14	12	16	4,107
12	17	23	6,530
10	24	32	10,380
8	33	46	16,510
6	46	65	26,250
5	54	77	33,100
4	65	92	41,740
3	76	110	52,630
2	90	131	66,370
1	107	156	83,690
0	127	185	105,500
00	150	220	133,100
000	177	262	167,800
0000	210	312	211,600
	200	300	200,000
	270	400	300,000
	330	500	400,000
	390	590	500,000
	450	680	600,000
	500	760	700,000
	550	840	800,000
	600	920	900,000
	650	1,000	1,000,000
	690	1,080	1,100,000
	730	1,150	1,200,000
	770	1,220	1,300,000
	810	1,290	1,400,000
	850	1,360	1,500,000
	890	1,430	1,600,000
	930	1,490	1,700,000
	970	1,550	1,800,000
	1,010	1,610	1,900,000
	1,050	1,670	2,000,000

Engineers, must be followed in placing interior conductors.

For insulated aluminum wire the safe carrying capacity is 84 per cent. of that given in the table for copper wire with the same kind of insulation.

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulation by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above table.

The carrying capacity of Nos. 16 and 18 B. & S. gauge wire is given, but no wire smaller than No. 14 is to be used, except as allowed for fixture work and flexible cord.

13. Wire Gauges.—It sometimes happens that wires of scant size are sold to the unwary. A workman constantly using wires of various sizes soon learns to gauge the size of wires by his eye, but it is better to use a wire gauge frequently to avoid mistakes. A wire of given size should just enter the slot intended for that size in the style of gauge shown in Fig. 10. Gauges in the form of a vernier caliper, measuring the diameter of the wire in thousandths of an inch, or **mils,*** are usually more accurate. Table II, giving the diameter in mils and cross-sectional area in

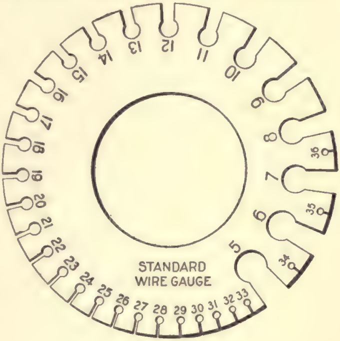


FIG. 10

*Diameters of wires are usually expressed in mils or thousandths of an inch and cross-sectional areas in circular mils. 1 mil = $\frac{1}{1000}$ inch = .001 inch. 1 circular mil is equal to the area of a circle of which the diameter is 1 mil and cross-sectional areas of wires are designated by the number of circular mils contained in their area. The circular mil is a more convenient unit than the square inch in which to express the areas of round wires since the number of circular mils bears a simple relation to the diameter in mils. If the diameter d is expressed in mils, then the number of circular mils cross-section is d^2. Thus, a No. 0000 wire, Table II, has a diameter of 460 mils, or .460 inch, and its area in circular mils is $460^2 = 211,600$. 1 square inch = 1,273,240 circular mils.

circular mils for the B. & S. sizes commonly used in interior-wiring work, is here inserted for convenient reference. The number of circular mils cross-section as given in this table is more accurate than in Table I, but the areas as given in Table I are close enough for all practical calculations.

TABLE II

DIMENSIONS OF BARE COPPER WIRE B. & S. GAUGE

Gauge Number	Diameter Mils	Area Circular Mils	Gauge Number	Diameter Mils	Area Circular Mils
0000	460.0	211,600.0	8	128.5	16,509.0
000	409.6	167,805.0	9	114.4	13,094.0
00	364.8	133,079.4	10	101.9	10,381.0
0	324.9	105,534.5	11	90.7	8,234.0
1	289.3	83,694.2	12	80.8	6,529.9
2	257.6	66,373.0	13	72.0	5,178.4
3	229.4	52,634.0	14	64.1	4,106.8
4	204.3	41,742.0	15	57.1	3,256.7
5	181.9	33,102.0	16	50.8	2,582.9
6	162.0	26,250.5	17	45.3	2,048.2
7	144.3	20,816.0	18	40.3	1,624.3

WIRING FOR LOW-POTENTIAL SYSTEMS

14. Definition of Low-Potential System.—

LOW-POTENTIAL SYSTEMS

550 Volts or Less

Any circuit attached to any machine or combination of machines that develops a difference of potential between any two wires of over 10 volts and less than 550 volts shall be considered as a low-potential circuit and as coming under this class, unless an approved transforming device is used that cuts the difference of potential down to 10 volts or less. The primary circuit not to exceed a potential of 3,500 volts.

Before pressure is raised above 300 volts on any previously existing system of wiring, the whole must be strictly brought up to all of the requirements of the rules at date.

Until recently, low-potential systems were limited to 300 volts or under, but the limit has been raised to 550. However, 550 volts cannot be applied to old systems unless the above rule is complied with. Low-potential systems are usually constant-potential systems also; that is, the potential or pressure between the terminals of the machine or at some definite points on the line is almost uniform. Only constant-potential systems will be considered under this heading.

A few general rules apply to the various kinds of work under these systems. They are as follows:

15. General Rules.—

Wires—

a. **Must be so arranged that under no circumstances shall there be a difference of potential of over 300 volts between any bare metal in any distributing switch, cut-out cabinet, or equivalent center of distribution.**

b. Must not be laid in plaster, cement, or similar finish and must never be fastened with staples.

c. Must not be fished for any great distance, and only in places where the inspector can satisfy himself that the rules have been complied with.

d. Twin wires must never be used, except in conduits or where flexible conductors are necessary.

e. Must be protected on side walls from mechanical injury. When crossing floor timbers in cellars or in rooms where they might be exposed to injury, wires must be attached by their insulating supports to the under side of a wooden strip not less than ½ inch in thickness and not less than 3 inches in width. Instead of the running boards, guard strips on each side of and close to the wires will be accepted. These strips to be not less than ⅞ inch in thickness, and at least as high as the insulators.

Suitable protection on side walls may be secured by a substantial boxing, retaining an air space of 1 inch around the

conductors, closed at the top (the wires passing through bushed holes), and extending not less than 5 feet from the floor; or by an iron-armored or metal-sheathed insulating conduit sufficiently strong to withstand the strain to which it will be subjected, and with the ends protected by the lining or by special insulated bushings, so as to prevent the possibility of cutting the wire insulation; or by plain metal pipe, lined with approved flexible tubing, which must extend from the insulator next below the pipe to the one next above it.

If metal conduits or iron pipes are used to protect wires carrying alternating currents, the two or more wires of each circuit *must* be placed in the same conduit as troublesome induction effects and heating of the pipe might otherwise result. And the insulation of each wire must be reenforced by approved flexible tubing extending from the insulator next below the pipe to the one next above it. This should also be done in direct-current wiring if there is any possibility of alternating current ever being used on the system.

For high-voltage work, or in damp places, the wooden boxing may be preferable, because of the precautions that would be necessary to secure proper insulation if the pipe were used. With these exceptions, however, iron pipe is considered preferable to the wooden boxing, and its use is strongly urged. It is especially suitable for the protection of wires near belts, pulleys, etc.

f. When run in unfinished attics, or in proximity to water tanks or pipes, will be considered as exposed to moisture.

16. The reason for the first part of (*b*) is that plaster and cement are likely to corrode the insulation on the wire and cause it finally to break. If the plaster is damp, leakage takes place, the wire is gradually dissolved by electrolysis, and finally it becomes so thin it cannot carry its current without excessive heating and, perhaps, not without melting. While there are many places where wires embedded in plaster have been used for years without serious trouble, because of the dryness of the buildings where they are in use, trouble may develop at any time and the practice is always a dangerous one.

The second part of (*b*) is inserted as a direct prohibition against running electric-light wires as bell wires are usually put up. Staples not only do not insulate the wire, but are likely to cut into the insulating covering already on it. Rule (*c*) is to prevent the location of wires where it is impossible to know that they are properly supported and insulated.

17. The suggestions regarding the protection of wires on side walls or other places where they are liable to be damaged, should be carefully noted. In interior wiring, one of the chief sources of risk is the currents that may flow from the wiring to ground if the insulation becomes defective. The danger from leakage currents either from wire to wire or from wires to ground is fully as great if not greater than that from overloaded wires or from actual short circuits between wires.

SYSTEMS OF DISTRIBUTION FOR INTERIOR WIRING

18. The voltages in common use on low-potential systems are: For direct currents, 110 and 220; for alternating currents, 104 to 110. These are used on both two-wire and three-wire systems. Many lighting companies allow for various amounts of drop at different points on their lines and install lamps of different voltages, as, for instance, 108-volt lamps near the generator and 100-volt lamps at the extreme end of the line, with lamps of intermediate voltages at intermediate points. But the lamps used in any one building are usually all of the same voltage.

19. The Two-Wire System.—This is the simplest plan of wiring and the one in most general use. Fig. 11 shows in diagram its essential features. The diagram of connections is the same for all voltages and for alternating or

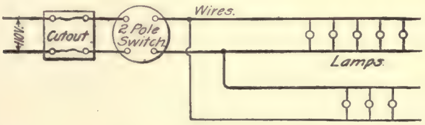


Fig. 11

direct currents; but the fittings, such as lamps, sockets, cut-outs, and switches, and the sizes of wire used will be very different. The fittings and the proper sizes of wire to be used will be discussed later.

20. The Edison Three-Wire System.—This system comes next in importance and extent of use; it also is used with various voltages and with direct or alternating currents. Usually the pressures are 110 volts between either outer wire and the middle or **neutral** wire and 220 volts between the outer wires. Fig. 12 shows the diagram of connections. This system is also sometimes installed with 220 volts between the neutral and outer wires and 440 volts between the outside wires.

Referring to the diagram, Fig. 12, observe the following: When the currents in the two outside wires are equal in amount, no current passes over the neutral wire; but when

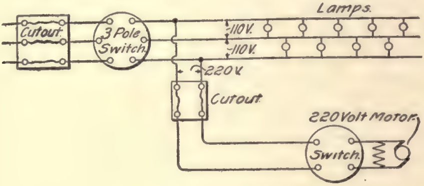


Fig. 12

the currents are not equal, that is, when more lamps or motors are on one side of the neutral wire than on the other, the "difference current" flows on the middle wire.

21. The advantage of this system is that with lamps of any given voltage it is possible to save in the amount of wire required. In the outside lines of the lighting company is where the greatest saving is effected, because the neutral wire is there much smaller than the outer ones, and three wires are used instead of four, which would have to be run if the generators were operated independently. In interior wiring, the saving is not so great, because the neutral wire must be large enough to carry the current in case all the load is turned off one side of the circuit, as would be the case if the fuse on one side should blow and that on the other side did not, and because in small installations, where unbalancing is likely to occur, three-wire mains must be large to reduce this trouble to a minimum.

22. The three-wire system also has some disadvantages. Its most objectionable feature is that if any one line is opened, as by the blowing of a fuse on one line only, the system is unbalanced and a voltage different from that intended for the apparatus is thrown on the lines, unless the line loss is very small indeed. If it is the middle wire that opens, the whole 220 volts may be thrown on 110-volt apparatus, if the system is much unbalanced. For this reason, some Edison companies refuse to place cut-outs on the neutral wire; but the main switch should in all cases open all three lines. Another weakness of the three-wire system is the fact that there is more danger in 220 volts than in 110, and a shock received from a 220-volt circuit may be very severe. The wiring is somewhat more complicated, but owing to the saving in line materials, the Edison three-wire system has been introduced to a very great extent and still meets with much favor in new installations, besides extending the network of its wires from existing stations. Lately it has had a new competitor in the 220-volt two-wire system, which has grown in popularity with the perfecting of the 220-volt incandescent lamp.

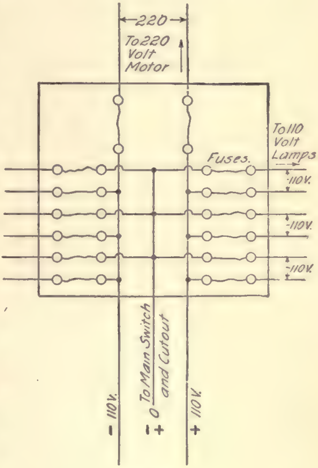


FIG. 13

23. It is the usual practice to run the three wires no farther within the building than to the centers of distribution, and from these centers to use the two-wire system, dividing the circuits as equally as possible on the two sides of the three-wire circuit, as shown in Fig. 13. By this

means, the branch lines are fused on both sides and amply protected against excessive currents, though not against high voltage. If the neutral wire within the building is protected by a fuse as large as that in either of the main wires, the danger of that line opening is very small.

24. A method of running wires on the two-wire plan that is sometimes confused with the three-wire system is illustrated in Fig. 14. In this method the middle wire carries the whole current, while each outside wire carries the current necessary for the lights on its side. This method effects no saving of copper; in fact, it often requires more than the two-wire system would, because the three wires must generally be of the same size, as explained under the subject of cut-out protection. The object of the arrangement is solely to make it possible to turn off a number of the lights without running four wires. The Underwriters will not permit it with more than 660 watts on a side.

25. House wiring should consist of two distinct portions: the **distribution circuits**, which run from the lamps to a **center of distribution** and which should always be two-wire circuits, and the **mains**, which run from the outside lines to the distribution center and which must conform to the requirements of the particular system to be used. If

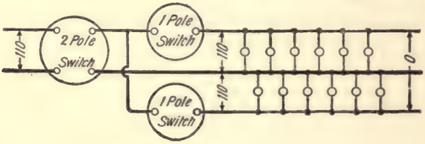


FIG. 14

mains must be installed before it is known what system is to supply current, it will be sufficient to run four wires of the size required were the lamps to be divided equally between two separate two-wire systems. This will make it possible to connect to any system operating at the voltage for which the wiring calculations are made.

SWITCHES AND CUT-OUTS

26. There are certain devices for the protection of constant-potential systems that are necessary no matter what voltage is used. Should anything happen to damage the wiring, it is necessary that the wires be disconnected from the source of supply of current with the least possible delay. The devices for this purpose that are operated by hand are called **switches.** Those that work automatically are called **automatic cut-outs.** These latter are of two kinds—**fuses** and **circuit-breakers.**

Both a switch and an automatic cut-out must be placed at or near the place where wires enter a building. They must also be placed at various other points on the wiring.

27. The object of the cut-out is to protect the wires and the devices connected to them from damage due to the presence of too much current from any cause whatever. The ordinary cut-out consists of a porcelain base that carries suitable terminals for holding a piece of fusible wire, or fuse, which melts and opens the circuit whenever the current becomes excessive. Not only must the cut-out protect the lines when there is trouble, but it must be so placed that it can be reached to replace the fuse or reset the circuit-breaker when the trouble is remedied. It must also be arranged so that the blowing of a fuse or the opening of a circuit-breaker cannot do any damage.

28. Switches are designed to disconnect the lines from the source of electricity, not only when there is trouble, but when convenience requires, as in turning off lights, starting and stopping motors.

Circuit-breakers are not as commonly used in interior-wiring work as are fusible cut-outs. They are automatic switches controlled by an electromagnet and are made in a number of different styles. Whenever the current exceeds

that for which the circuit-breaker is adjusted, the electromagnet attracts its armature and releases the switch, thus opening the circuit.

The following rules regarding these devices must be observed in all cases:

Switches, Cut-Outs, Circuit-Breakers, Etc.—

a. Must, whenever called for, unless otherwise provided, be so arranged that the cut-outs will protect, and the opening of the switch or circuit-breaker will disconnect, all the wires; that is, in a two-wire system the two wires, and in a three-wire system the three wires, must be protected by the cut-out and disconnected by the operation of the switch or circuit-breaker.

b. Must not be placed in the immediate vicinity of easily ignitible stuff or where exposed to inflammable gases or dust or to flyings of combustible material.

In starch and candy factories, grain elevators, flouring mills, and buildings used for woodworking or other purposes that would cause the fittings to be exposed to dust and flyings of inflammable material, the cut-outs and switches should be placed in approved cabinets outside of the dust rooms. If, however, it is necessary to locate them in the dust rooms, the cabinets must be dust-proof and must be provided with self-closing doors.

c. Must, when exposed to dampness, either be enclosed in a waterproof box or mounted on porcelain knobs.

d. Time switches must be enclosed in an iron box, or cabinet lined with fire-resisting material.

If an iron box is used, the minimum thickness of the iron must be .128 inch (No. 8 B. & S. gauge).

If cabinet is used, it must be lined with marble or slate at least $\frac{3}{8}$ inch thick, or with iron not less than .128 inch thick. Box or cabinet must be so constructed that when switch operates, blade shall clear the door by at least 1 inch.

Automatic Cut-Outs (Fuses and Circuit-Breakers)

Excepting on main switchboards, or where otherwise subject to expert supervision, circuit-breakers will not be accepted unless fuses are also provided.

a. Must be placed on all service wires, either overhead or underground, as near as possible to the

point where they enter the building and inside the walls, and arranged to cut off the entire current from the building.

Where the required switch is inside the building, the cut-out required by this section must be placed so as to protect it.

In risks having private plants, the yard wires running from building to building are not generally considered as service wires, so that cut-outs would not be required where the wires enter buildings, provided that the next fuse back is small enough to properly protect the wires inside the building in question.

b. Must be placed at every point where a change is made in the size of wire (unless the cut-out in the larger wire will protect the smaller).

29. The object of a fusible cut-out is to protect the wire; therefore, it must be placed so that all the current that flows through the wire to be protected will also pass through the cut-out. The fuse is proportioned so that its carrying capacity will not exceed the carrying capacity of the wire, as given in Table I; hence, if an excessive current flows, the fuse will melt and open the circuit before the wire becomes overheated. If a branch wire, say No. 14, were connected to a main, say No. 10, and if no cut-out were placed at the junction, it is plain that, since the fuse in the No. 10 wire has a carrying capacity in excess of that allowed for No. 14, a short circuit or overload on the branch line might cause overheating of the No. 14 wire. Very often, however, the fuse in the larger wire is of such size that it protects the smaller wire, in which case it is not necessary to place a fuse at the junction point. For example, take the case where No. 14 wire at a fixture outlet is attached to the fixture wiring. The wire in the fixture is usually No. 16 or No. 18 in order that it may pass between the gas pipe and the outer shell, but the fuse in the cut-out or on the panel board at the distributing center is proportioned in accordance with the carrying capacity of the fixture wire instead of the No. 14 wire running from the panel board or cut-out to the fixture; hence, in this case the fuse in the larger wire protects the smaller wire and a cut-out in the

fixture canopy where the fixture wire attaches to the No. 14 lines is unnecessary; in fact, fixture cut-outs are prohibited by rule (*c*) given below.

> *c.* Must be in plain sight or enclosed in an approved cabinet and readily accessible. They must not be placed in the canopies or shells of fixtures.
>
> The ordinary porcelain link-fuse cut-out will not be approved. Link fuses may be used only when mounted on approved slate or marble bases and must be enclosed in dust-tight, fireproof cabinets, except on switchboards located well away from combustible material, as in the ordinary engine and dynamo room where these conditions will be maintained.

30. Rule (*c*) is important. It prohibits the use of the small cut-outs that were formerly placed in the canopies of fixtures in order to protect the fixture wiring. These cut-outs gave a great deal of trouble and introduced a fire risk that more than offset any advantage they might have had. It has been found safer and more satisfactory, therefore, to omit them and let the fuse in the cut-out on the branch main leading to the fixture afford the protection, as explained under rule (*b*).

It should also be noted that this rule prohibits the use of the ordinary porcelain link-fuse cut-outs that were, until recently, very largely used for the protection of circuits. The link fuse consists of a piece of fuse wire or strip provided with copper terminals, the fuse wire or strip being exposed to the air. These fuses were held between suitable terminals mounted on a porcelain base. The use of link fuses is still permitted when they are mounted on slate or marble distributing boards and placed in fireproof cabinets, but the link-fuse porcelain cut-out is no longer permitted and it is now necessary to use enclosed fuses instead. Enclosed fuses and link fuses will be described in detail when fittings are taken up.

> *d.* Must be so placed that no set of incandescent lamps requiring more than 660 watts, whether grouped on one fixture or on several fixtures, or

pendants, will be dependent on one cut-out. Special permission may be given in writing by the Inspection Department having jurisdiction for departure from this rule in the case of large chandeliers, stage borders, and illuminated signs.

The above rule shall also apply to motors when more than one is dependent on a single cut-out.

The idea is to have a small fuse to protect the lamp socket and the small wire used for fixtures, pendants, etc. It also lessens the chances of extinguishing a large number of lights if a short circuit occurs.

On open work in large mills, approved link-fused rosettes may be used at a voltage of not over 125, and approved enclosed-fused rosettes at a voltage of not over 250, the fuse in the rosettes not to exceed 3 amperes, and a fuse of over 25 amperes must not be used in the branch circuit.

All branches, or taps, from a three-wire Edison system must be run as two-wire circuits.

31. Rule (*d*) is very important because it limits the number of lamps that may be operated on any one circuit. On 110-volt circuits, 660 watts is equivalent to not more than twelve 16-candlepower lamps; on 220-volt circuits not more than ten 16-candlepower lamps. It is best not to exceed ten lamps to a circuit except in the special cases mentioned in the rule. The fused rosettes referred to under rule (*d*) are small porcelain cut-outs from which the lamps are suspended. It should be particularly noted that these rosettes are not allowed on pressures higher than 125 volts unless they are provided with enclosed fuses.

Rule (*d*) also applies to motors when more than one motor is dependent on a single cut-out. This refers particularly to fan motors, as most motors for power purposes will be over 660 watts capacity and each motor will therefore require a branch circuit and cut-out of its own.

e. The rated capacity of fuses must not exceed the allowable carrying capacity of the wire. Circuit-breakers must not be set more than 30 per cent. above the allowable carrying capacity of the wire, unless a fusible cut-out is also installed in the circuit.

This is very important. A fuse block not properly fused is of no use whatever. Irresponsible parties sometimes place fuses much too large to protect the wire and which

would destroy the cut-out if they should ever blow, besides doing other damage. Sometimes, also, fuse blocks are found having copper wire where the fuses should be; of course, they are of no use with such connections. The common custom of fusing with wire much larger than that allowable is one of the reasons for the prohibition of link-fuse porcelain-base cut-outs. The bases used with enclosed fuses are not easily fused with any wire that may be convenient because the terminals are not suited to a wire fuse. Note that rule (*e*) fixes the maximum size of fuse to be used on any circuit by the carrying capacity of the wire protected and not by the current required for operating the devices used on the circuit. For example, the carrying capacity of a No. 14 rubber-covered wire is 12 amperes and the rated capacity of the fuse used on a No. 14 circuit could be as high as 12 amperes without breaking the rule, though there might only be ten 110-volt lamps on the circuit requiring a current of about 5 amperes for their operation.

Cut-outs should always be installed in a location where they can be easily reached for the replacement of fuses. This is a point too often neglected in the laying out of interior wiring, particularly for small houses where regular distributing panel boards are not used.

When arc lamps are operated on constant-potential circuits, each lamp must be provided with a cut-out and the branch conductors leading from the mains to the lamps should have a carrying capacity about 50 per cent. in excess of the normal current in order to allow for the increased current required when the lamp is started or when the carbons become stuck. If each lamp is not fed by a separate branch circuit running from a panel board or fuse cabinet, it is necessary to locate an enclosed-fuse cut-out at the point where the wires leave the mains for a lamp.

32. Circuit-breakers may be set so as to work with greater accuracy than fuses; they respond more quickly to sudden overloads, for fuses require a little time to get hot enough to melt. For this reason, circuit-breakers may

be set for higher currents than fuses. If they are not so set, they will give trouble by opening the circuit on momentary overloads that would not be sufficient to melt the fuses. Circuit-breakers are usually installed to protect machines, such as motors and dynamos; they are not used for the protection of the branch distribution circuits in buildings because the rules require that they shall only be used in such places where they will at all times be under expert supervision.

33. Rules Relating to Switches.—

Switches—

a. Must be placed on all service wires, either overhead or underground, in a readily accessible place, as near as possible to the point where the wires enter the building, and arranged to cut off the entire current.

Service cut-out and switch must be arranged to cut off current from all devices, including meters.

In risks having private plants, the yard wires running from building to building are not generally considered as service wires, so that switches would not be required in each building if there are other switches conveniently located on the mains or if the generators are near at hand.

b. Must always be placed in dry, accessible places and be grouped as far as possible. Knife switches must be so placed that gravity will tend to open rather than close them.

When possible, switches should be so wired that blades will be "dead" when switch is open.

If knife switches are used in rooms where combustible flyings would be likely to accumulate around them, they should be enclosed in dust-tight cabinets. Even in rooms where there is no combustible material it is better to put all knife switches in cabinets, in order to lessen the danger of accidental short circuits being made across their exposed metal parts by careless workmen.

Up to 250 volts and 30 amperes, approved indicating snap switches are advised in preference to knife switches on lighting circuits about the workrooms.

c. Must not be single-pole when the circuits that they control supply devices that require over 660 watts of energy or when the difference of potential is over 300 volts.

This rule (*c*) is important, because it restricts so severely the number of lamps that may be controlled by a single-pole switch.

d. Where flush switches are used, whether with conduit systems or not, the switches must be enclosed in boxes constructed of or lined with fire-resisting material. No push buttons for bells, gas-lighting circuits, or the like shall be placed in the same wall plate with switches controlling electric-light or power wiring.

This requires an approved box in addition to the porcelain enclosure of the switch.

e. Where possible, at all switch or fixture outlets, a $\frac{7}{8}$-inch block must be fastened between studs or floor timbers, flush with the back of lathing, to hold tubes and to support switches or fixtures. When this cannot be done, wooden base blocks not less than $\frac{3}{4}$ inch in thickness, securely screwed to the lathing, must be provided for switches and also for fixtures that are not attached to gas pipes or conduit tubing.

34. Construction of Cut-Outs, Circuit-Breakers, Etc.—The rules that have just been given relate to the location and installation of cut-outs, circuit-breakers, switches, etc. In addition to these rules there are a large number of Underwriters' rules that relate to the construction of these devices, but for the most part these concern the manufacturer rather than the wireman. A few only of the more important of these rules will be given here as a general guide to the wireman.

Cut-Outs and Circuit-Breakers—

a. Must be supported on bases of non-combustible, non-absorptive, insulating material.

b. Cut-outs must be of plug or cartridge type, when not arranged in approved cabinets, so as to obviate any danger of the melted fuse metal coming in contact with any substance that might be ignited thereby.

c. Cut-outs must operate successfully on short circuits, under the most severe conditions with which they are liable to meet in practice, at 25 per cent. above their rated voltage, and with fuses rated at 50 per cent. above the current for which the cut-out is designed.

d. Circuit-breakers must operate successfully on short circuits, under the most severe conditions with which they are liable to meet in practice, when set at 50 per cent. above the current, and with a voltage 25 per cent. above that for which they are designed.

e. Must be plainly marked, where it will always be visible, with the name of the maker and the current and voltage for which the device is designed.

Snap Switches.—

a. Current-carrying parts must be mounted on non-combustible, non-absorptive, insulating bases, such as slate or porcelain, and the holes for supporting screws should be countersunk not less than $\frac{1}{8}$ inch; in no case must there be less than $\frac{3}{64}$ inch space between supporting screws and current-carrying parts.

Subbases, of non-combustible, non-absorptive insulating material, that will separate the wires at least $\frac{1}{2}$ inch from the surface wired over should be furnished for all snap switches used in exposed knob or cleat work.

b. Covers made of conducting material, except face plates for flush switches, must be lined on their sides and top with insulating, tough, and tenacious material at least $\frac{1}{32}$ inch in thickness, firmly secured, so that it will not fall out with ordinary handling. Side lining should extend slightly beyond the lower edge of the cover.

c. The handle, button, or any exposed part must not be in electrical connection with the circuit.

Switches that indicate, upon inspection, whether the current be "on" or "off" are recommended.

Some of the common styles of switches and cut-outs will be described later when the methods of wiring are taken up.

OPEN WORK IN DRY PLACES

35. Open work is generally used in factories, warehouses, mills, and other places where there is no objection to having the wires in plain sight, or in old buildings, where the expense of concealed work overbalances the objectionable appearance in the mind of the owner. It is the cheapest kind of construction and very often the safest. This method of wiring will be explained by means of simple examples.

SIMPLE EXAMPLE OF FACTORY WIRING

36. Consider a factory, such as a long machine shop, where there is but one floor to be wired for 110-volt enclosed-arc lamps and incandescent lamps on the so-called **tree system**; that is. with but one set of mains or feeder wires leaving the dynamo and with other lines branching from these mains to the points where lamps are required.

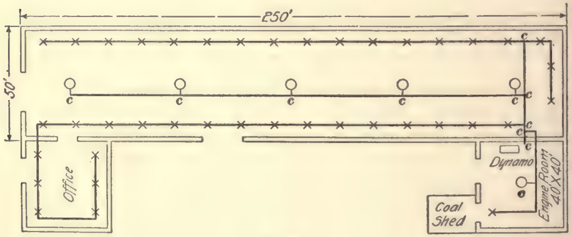


FIG. 15

Let Fig. 15 represent the outlines of such a factory, in which incandescent lamps are to be hung on lamp cord at the points marked × and enclosed-arc lamps are to be placed where the marks ○ are shown. After finding the cheapest way in which this factory can be wired in order to satisfy

the Underwriters, we will see what modifications can be made to better the light, improve the system, and make it more convenient and economical in operation.

37. Assume that each 16-candlepower incandescent lamp requires 55 watts; some good lamps take less power, but it is not safe to count on less. Also assume that each enclosed arc is to take 5 amperes while burning and 12 amperes to start on. There are 40 incandescent lamps and 6 arc lamps to be wired.

$$
\begin{aligned}
&55 \text{ (watts)} \div 110 \text{ (volts)} = .5 \text{ (ampere per lamp)}\\
&40 \times .5 = 20 \text{ (amperes for incandescent lamps)}\\
&6 \times 5 = \underline{30} \text{ (amperes for arc lamps)}\\
&\text{Total amperes} = 50
\end{aligned}
$$

which must be carried on the mains for a short distance at least.

Referring to Table I, we see that the smallest wire that will carry 50 amperes with safety is No. 6 weather-proof.

38. Rules Relating to Wires for Open Work.—For open work in dry places we have in addition to the general rules relating to wires, the following special rules regarding wires used in open work:

Wires—

a. Must have an approved rubber or "slow-burning" weather-proof insulation.

b. Must be rigidly supported on non-combustible, non-absorptive insulators that will separate the wires from each other and from the surface wired over in accordance with the following table:

Voltage	Distance From Surface Inch	Distance Between Wires Inches
0 to 300	$\frac{1}{2}$	$2\frac{1}{2}$
300 to 500	1	4

Rigid supporting requires under ordinary conditions, where wiring along flat surfaces, supports at least every $4\frac{1}{2}$ feet. If the wires are liable to be disturbed, the distance between supports should be shortened. In buildings of mill construction, mains of No. 8 B. & S. wire or over, where not liable to be disturbed, may be separated about 4 inches and run from timber to timber, not breaking around, and may be supported at each timber only.

This rule will not be interpreted to forbid the placing of the neutral of a three-wire system in the center of a three-wire cleat, provided the outside wires are separated $2\frac{1}{2}$ inches.

39. Rubber-covered wire used for interior-wiring work consists of a tinned copper wire with a covering of rubber with an outer braiding of cotton soaked in preservative compound. For voltages up to 600 and for sizes of wire from No. 15 to No. 0000 the thickness of insulation varies from $\frac{3}{64}$ inch to $\frac{5}{64}$ inch, being thinner on the smaller sizes of wire.

40. Slow-burning weather-proof wire is less expensive than rubber-covered and is good enough for open work in dry places where the wire is in contact with insulating supports only, as in the case with the example of factory wiring now under consideration. This wire is provided with two coatings, one of which is fireproof in character and the other weather-proof. Most of this wire was formerly made with weather-proof braid on the outside, but the Underwriters now require the fireproof braid to be placed on the outside, and the compound with which it is treated slicked down so that the wire will have a hard, dense finish. The Underwriters lay down specifications to which the various kinds of wire must conform. Wire obtained from almost any reputable manufacturer meets the requirements, so it will not be necessary to give the specifications here.

Owing to the fact that ordinary weather-proof wire and fireproof and weather-proof are much cheaper than rubber-covered, there is a tendency on the part of the unscrupulous contractors to use these wires in places where rubber-covered wire only should be used. They are not allowable for concealed work or for open work where dampness is present. Fireproof and weather-proof wire is not so liable to burn as the old weather-proof, which had but one or more braidings

soaked in weather-proof compound, and it is able to repel the ordinary amount of moisture found indoors. It is not suitable for outside line work. In general, fireproof and weather-proof wire can be used only in those cases where the insulating supports on which the wire is mounted are depended on for insulation, the covering being regarded simply as a precaution against accidental contact with other wires or any other objects. With rubber-insulated wire, the covering may in some cases be depended on altogether for the requisite insulation, as, for example, where the wires constituting the two sides of a circuit are drawn through a system of pipes or conduits.

41. Determination of Sizes of Wire According to Current Capacity.—Observing the location of the lamps as shown in the diagram, Fig. 15, it is seen that on each side of the building and down the center they are arranged in straight lines. Therefore, it will be easier to run the wires along these lines and to fasten the rosettes (small porcelain fittings from which the lamps are suspended) directly to them, rather than put in short branch lines and run the principal wires in any other way. The wires will therefore be run as shown in the sketch, where each line is supposed to represent a pair of wires put up on knobs or cleats.

Eighteen incandescent lamps are on one line, twenty-one on another, five arc lamps on a third, and one arc lamp and one incandescent lamp on a fourth. Referring again to Table I, we find that these lines will require wires of the following sizes: Twenty-one incandescent lamps (10.5 amperes), No. 14 wire; eighteen incandescent lamps (9 amperes), No. 14 wire; five arc lamps (25 amperes), No. 10 wire; one arc lamp and one incandescent lamp (5.5 amperes), No. 14 wire.

42. Location of Cut-Outs.—Since not more than 660 watts can be dependent on one cut-out, if we lay out the wiring as stated thus far it will be necessary to have fuses in all the rosettes and also a separate cut-out *c* at each arc lamp. There must also be a cut-out at the point where

each branch line joins the mains. The small wires running from the cut-outs to the arc lamps may be No. 14, which is large enough to carry the starting current of 12 amperes continually, if necessary. The main switch and cut-out should be located near the dynamo in the engine room. The wiring as now laid out, if put up properly, will comply with all the Underwriters' rules, but it will not necessarily give satisfaction; it will merely be safe. But before entering on the matter of how to improve the plan of the wiring, we will consider some of the fittings and methods of work that should be used on an installation of this kind.

FIG. 19

FITTINGS USED FOR EXPOSED WIRING

43. Open work must always be put up as though there were no insulation whatever on the wires themselves. The wires must be supported on insulators so as not to come

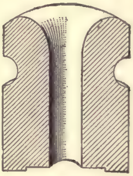


FIG. 16

FIG. 17

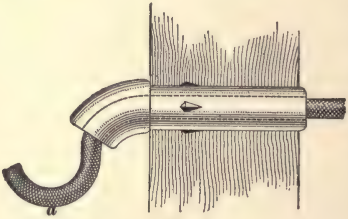


FIG. 18

into contact with any woodwork, pipes, or any other thing except insulating supports.

44. Fittings for Supporting Wire.—Some varieties of porcelain fittings suitable for this kind of work are shown in Figs. 16 to 25, inclusive. Fittings quite different in design may be used if they comply with the rules.

Fig. 16 shows an ordinary porcelain **knob,** in section; these are made in various sizes, and the size used will depend somewhat on the size of wire to be accommodated.

Fig. 17 shows the common, 4-inch, porcelain **tube** used where wires are run through joists. Fig. 18 is the style of tube used where wires are brought through window frames from the outside. The end is curved downwards to prevent water running in, and the *drip loop a* is formed to allow the water to drip off. A similar tube, only longer, is used for bringing wires in through brick or stone walls. Fig. 19 is a long, straight, porcelain tube used for passing through walls or floors.

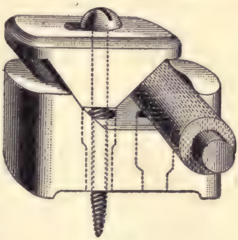


Fig. 20

Note that the head *a* is some distance from the end, so that when the tube is used for carrying wires through floors the exposed part of the wire will be above the floor.

Fig. 20 is a single-wire **cleat,** used mostly for supporting fairly large wires. Fig. 21 shows a two-wire cleat designed to

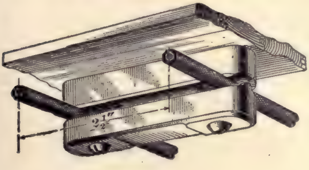


Fig. 21

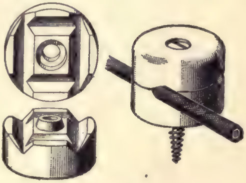


Fig. 22

support the wires 2½ inches apart, in order to conform with the Underwriters' requirements. Many other cleats are made, but they are much the same in general construction. It is always best to put up cleats and knobs with screws, as a

better job is done than when nails are used; nails are, however, sometimes used, a leather washer being placed between the nail head and the porcelain, to prevent the latter from being cracked. Fig. 22 is a **knob cleat** used for supporting

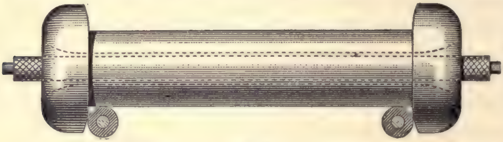


FIG. 23

single wires where something neater than the ordinary knob is desired. It does away with the necessity of a tie-wire and is provided with four different sized grooves so that it will accommodate wires of various thicknesses. Fig. 23 shows a double-headed tube used when wires cross each other. Porcelain tubes should always be used where crossings of this kind occur. The tube shown in Fig. 17 is frequently used for this purpose; but if this is done, the end without a head should be taped to the wire to prevent the tube sliding along.

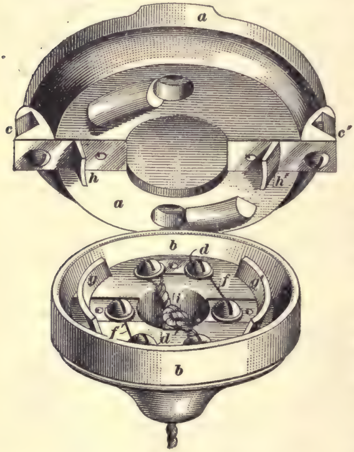


FIG. 24

Fig. 24 shows a fused **rosette** or ceiling cut-out made in two parts, *a* and *b*. Part *a* is screwed to the ceiling and the lamp is hung from the cap *b*. The lines are attached to the terminals c, c' and the lamp cord to d, d'; f, f' are the small fuses. When the cover *b* is attached to *a* by a twisting movement, terminals g, g' lock with h, h' and make the

connection from the mains to the lamp. The cord should be knotted at *i* so that the pull will not come on the connections *d*, *d'*. Rosettes with link fuses, as shown in Fig. 24, must not be used on pressures over 125 volts or for more than 3 amperes. They must not be located where inflammable flyings or dust will accumulate on them and the next fuses back of them must not be of over 25 amperes capacity, as the rosettes cannot safely break large currents. Fused rosettes are not advised where drop cords can be properly protected by line cut-outs. With the layout shown in Fig. 15, it will be necessary to use fused rosettes for the incandescent lamps. Cut-outs of the plug or cartridge type would be necessary for the arc lamps because the current for each lamp exceeds the maximum of 3 amperes allowed for the rosettes.

45. For such work as is now being considered, the principal porcelain articles required are the cleat, the rosette, and the cut-out, all of which are made in several forms. The selection of such fittings must be made with reference to the work in hand.

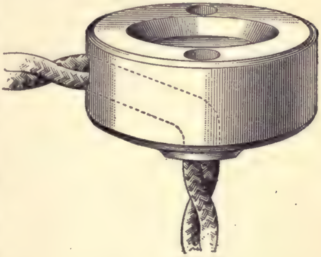


Fig. 25

If the wires are placed high out of reach and the distance between the points of support is considerable, they should be separated a foot or more and fastened to knobs. Where passing through walls or partitions, the wires should be protected by porcelain bushings.

If a lamp is needed not more than 3 feet from the direct line of the wires, it can be hung where required by means of a **ceiling button,** Fig. 25; but lamp cord must not be used to run lamps in this way more than 2 or 3 feet from the rosette.

46. Flexible Lamp Cord.—In selecting lamp cord for this kind of work and in securing good sockets, too much

care cannot be taken, for trouble occurs more frequently in lamp cord and sockets than in any other part of the wiring, if these articles are not of the highest grade. There is much temptation to use lamp cord for purposes other than those for which it is designed. The rules regarding it are given here, and special attention is directed to them:

Flexible Cord—

a. Must have an approved insulation and covering.

b. Must not be used where the difference of potential between the two wires is over 300 volts.

c. Must not be used as a support for clusters.

d. Must not be used except for pendants, wiring of fixtures, and portable lamps or motors, and portable heating apparatus.

The practice of making the pendants unnecessarily long and then looping them up with cord adjusters is strongly advised against. It offers a temptation to carry about lamps that are intended to hang freely in the air, and the cord adjusters wear off the insulation very rapidly.

For all portable work, including those pendants that are liable to be moved about sufficiently to come in contact with surrounding objects, flexible wires and cables especially designed to withstand this severe service are on the market and should be used.

The standard socket is threaded for $\frac{1}{8}$-inch pipe, and if it is properly bushed, the reenforced flexible cord will not go into it; but this style of cord may be used with sockets threaded for $\frac{3}{8}$-inch pipe and provided with substantial bushings. The cable is to be supported, independent of the overhead circuit, by a single cleat, and the two conductors then separated and soldered to the overhead wires.

The bulb of an incandescent lamp frequently becomes hot enough to ignite paper, cotton, and similar readily ignitible materials, and in order to prevent it from coming in contact with such materials, as well as to protect it from breakage, every portable lamp should be surrounded with a substantial wire guard.

e. Must not be used in show windows.

f. Must be protected by insulating bushings where the cord enters the socket.

g. Must be so suspended that the entire weight of the socket and lamp will be borne by knots under the bushing in the socket, and above the point where the cord comes through the ceiling block or rosette, in order that the strain may be taken from the joints and binding screws.

47. In selecting flexible cord for any given job of wiring, the class of work for which the cord is to be used must be kept in view.

The following rule specifies the kind of insulated cord that must be used with portable apparatus.

For portable lamps, small motors, etc.:

> *a.* Flexible cord for portable use must meet all the requirements for flexible cord for pendant lamps both as to construction and thickness of insulation, and in addition must have a tough braided cover over the whole. There must also be an extra layer of rubber between the outer cover and the flexible cord, and in most places the outer cover must be saturated with a moisture-proof compound thoroughly slicked down. In offices, dwellings, or in similar places where appearance is an essential feature, a silk braid may be substituted for the weather-proof braid.

48. Lamp Bases.—The style of lamp socket used in a given job of wiring will depend on the kind of **lamp base** used on the system. A large number of different styles of lamp bases have been brought out, but the number has gradually been cut down until the three types shown in

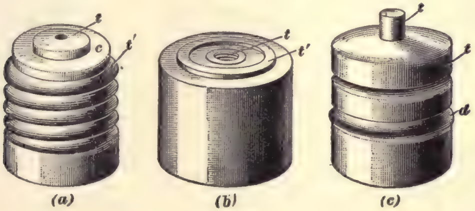


FIG. 26

Fig. 26 cover practically all the lamps in use in the United States; these are the Edison (*a*), the Thomson-Houston (*b*), and the Sawyer-Man, or Westinghouse (*c*). Of these three, the Edison base is the most popular and is rapidly superseding the other two. In each case, the terminals of the

socket are marked t, t'. When the lamp is placed in the socket, these make connection with corresponding terminals, thus connecting the circuit with the lamp.

49. Lamp Sockets and Receptacles.—A large variety of lamp sockets are manufactured, but they are all much the same in general design. Some of these are provided with

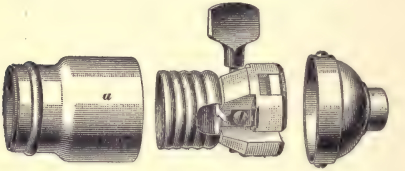


FIG. 27

FIG. 28

keys for turning the light off or on; others are keyless—the light being controlled by a separate switch. The main thing to look out for in selecting sockets is to see that they are substantial; one of the most common sources of trouble on incandescent-lighting circuits is flimsy sockets that are continually getting out of order. Fig. 27 shows a typical

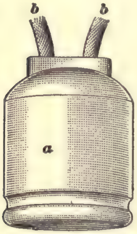
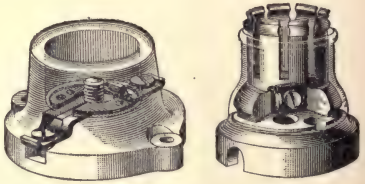


FIG. 29



(a) (b)

FIG. 30

key socket for an Edison base lamp. Sockets should be so constructed that the shell *a* will be insulated from the wires. The rubber or composition bushing shown in Fig. 28 must be used to protect the cord where it passes through the shell. Ordinary key sockets are suitable for work with incandescent lamps not exceeding 32 candlepower.

Fig. 29 shows a waterproof, keyless socket for an Edison base. The shell *a* is of porcelain and the wires *b*, *b* are attached directly to the mains. Sockets of this type are required by the Underwriters whenever wiring is done in damp places, such as breweries, dye houses, etc.

Fig. 30 (*a*) and (*b*) shows two styles of keyless receptacles. That shown in Fig. 30 (*a*) is almost entirely of porcelain and is designed for a lamp having a Thomson-Houston (T. H.) base. That shown in Fig. 30 (*b*) is provided with a porcelain base and a brass shell, the terminals being designed to take a Sawyer-Man, or Westinghouse, base.

CURRENT REQUIRED FOR LAMPS

50. In making wiring calculations, it is necessary to know the current taken by the lamps. This varies somewhat with different makes and can be calculated exactly if the watts per candlepower are known. For ordinary calculations, it will be found convenient to use the current given

TABLE III

POWER CONSUMPTION OF INCANDESCENT LAMPS

Candlepower	Voltage	Current Amperes	Watts
8	110	.27	30
10	110	.32	35
16	110	.50	55
16	52	1.00	52
16	220	.30	66
32	110	1.00	110

in Table III. The current taken by enclosed arc lamps varies with the make and size of lamp. About 5 amperes is a fair average for constant-potential enclosed arcs, though in some cases lamps may be designed for 6 amperes, while in others where a long arc is used, the current may be as low as 4 amperes.

FUSES

51. Link Fuses.—Fig. 31 shows an ordinary link fuse consisting of a fusible wire or strip *c* (generally made of a mixture of lead and tin) provided with copper terminals *a*, *b*. The terminals are necessary in order to provide good contact between the fuse and the fuse-block terminals; and, also, to prevent damage to the soft fuse wire from the clamping screws. Link fuses are gradually going out of use; they are not as reliable as enclosed fuses of the plug or cartridge types and are no longer allowed except in rosettes where the current must not exceed 3 amperes, or on panel boards that are mounted in fireproof cabinets. Even on panel boards, the best practice is to use enclosed fuses in preference to those of the link type even though the

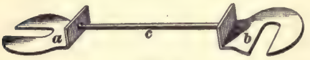


FIG. 31

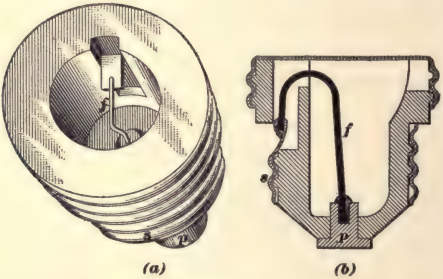


FIG. 32

latter are not prohibited. For all fuses mounted on porcelain bases and used outside of cabinets, the enclosed type must now be used.

52. Enclosed Fuses.—The oldest type of enclosed fuse is the Edison **plug,** Fig. 32. They are used on 125-volt circuits and are made for currents from 3 amperes to 30 amperes. They are also allowable on three-wire circuits with grounded neutral where the pressure between the outside wires does

not exceed 250 volts. The fuse *f*, Fig. 32, is mounted in a procelain holder and attached to the screw terminal *s* and the contact *p*; the holder is provided with a brass cap with an opening covered with mica or with a plain cap without mica.

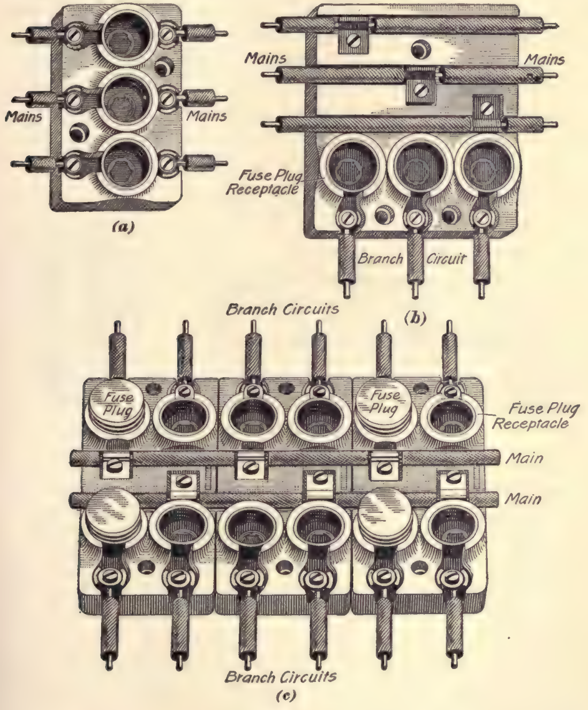


FIG. 33

These plugs screw into the receptacles on the fuse block, and whenever a fuse blows, a new plug is inserted.

Fig. 33 (*a*) shows a three-wire **main block** and (*b*) a three-wire **branch block**; (*c*) shows three two-wire **double**

branch blocks grouped together to form a distributing center. The advantages of this type of fuse are that it is enclosed and that it gives good contact between the fuse and the fuse-block terminals.

53. Most enclosed fuses are of the so-called **cartridge type,** shown in Fig. 34. The enclosed fuse consists essentially of an insulating tube provided with metal ends *b*, *b* that fit into clips *c*, *c* when the tube is placed in position. The fuse wire (which is often made of zinc or aluminum) passes through this tube and is surrounded with a non-conducting material that will flux with the molten metal and effectually suppress the arc. One objection that has been

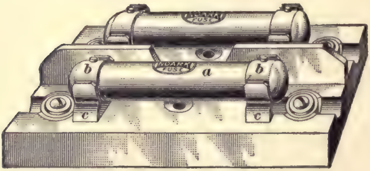


FIG. 34

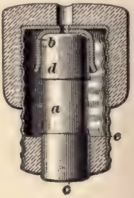


FIG. 35

urged against enclosed fuses, outside of their higher cost as compared with link fuses, is the difficulty in telling whether a fuse has blown or not since it is enclosed and cannot be seen. In the type of fuse shown in Fig. 34 this difficulty is overcome by shunting the main fuse by a small wire that runs under a label on the cartridge. When the main fuse blows, the small wire at once melts and makes a mark on the label.

Fig. 35 shows an adaptation of the cartridge type of fuse to the Edison plug. Cut-outs already installed for use with Edison plug fuses can thus be made to serve for cartridge fuses and can be used for pressures as high as 250 volts. The small cartridge fuse *a* is pushed through the hole in the bottom of the plug and is held by the clip *b* so that when the plug is screwed in place the current passes through the fuse by way of the contacts *c*, *d*, *e*. When a fuse blows, it is

necessary to replace the cartridge only and not the whole plug as with the Edison plug fuse.

54. The chief advantages of enclosed fuses are that they are more reliable than link fuses and prevent arcing. The fuse wire is not exposed to air-currents and it is impossible for it to come in contact with substances other than those for which the fuse was originally designed and adjusted. Manufacturers of enclosed fuses make arrangements for refilling the cartridges, so that the expense of using these fuses is not as great as their first cost would indicate.

55. Rating of Fuses.—Every fuse must be marked with the rated current that it is designed to carry and also the voltage of the circuit for which it is intended. The rated current is not the current at which the fuse will open the circuit. According to the National Code, fuses must be constructed so that with the surrounding air at a temperature of 75° F. they will carry indefinitely a current 10 per cent. greater than that at which they are rated, and at a current 25 per cent. greater than the rating, they will open the circuit without reaching a temperature that will injure the fuse tube or terminals of the fuse block.

WIRING FOR A UNIFORM DROP

56. In the method of wiring illustrated in Fig. 15, the lamp on the extreme end of the line in the office is much farther from the dynamo than the first lamp on that line. Owing to the resistance of the wire, the distant lamp will not burn as brilliantly as the nearer one; therefore, it is desirable to have a system of wiring on which the lamps will all glow with equal brightness. Also, it is not desirable, in many cases, to have a rosette with a fuse at each lamp, as this means many small fuses, and many very small fuses, besides causing more trouble, are not as reliable as a few larger ones. Fig. 36 represents the factory wired so as to avoid these two undesirable conditions. Where joints are made without changing the size of the wire, no cut-outs are

required. In these wiring diagrams but one line is drawn to represent the two wires that must be installed.

In the wiring diagram shown in Fig. 36, there being less than 660 watts on any branch circuit, fuses may be omitted from the rosettes (or fuseless rosettes installed). Fuses of a proper size to protect the lamp cord must be placed in the cut-outs, that is, 6-ampere fuses if No. 16 cord is used. In

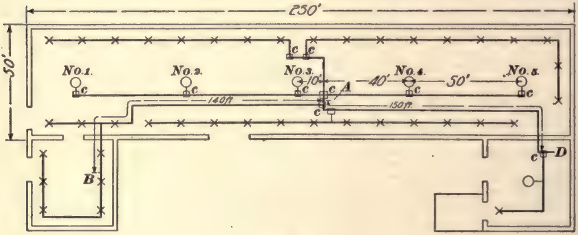


FIG. 36

such an installation, No. 18 lamp cord cannot be used without fused rosettes, unless not more than six lamps are placed on a branch circuit, because a 3-ampere fuse is required to protect No. 18 wire, and if placed in a cut-out, it will not allow current to pass for more than six 110-volt lamps. The sizes of wires permitted by the insurance rules will be the same as in the first case studied.

57. We will now take up the subject of line calculations with reference to loss of power, or **drop** in potential. Table IV gives the resistance of pure copper wire at 75° F. (24° C.), which is the temperature at which wiring calculations are usually made. The conductivity of commercial copper wire is from 98 to 99.5 per cent. of that of pure copper.

In ordinary interior wiring, the variations in resistance due to changes in temperature are usually disregarded, although they must be taken into account in the design of most kinds of electrical apparatus where they affect the regulation very much, as, for instance, in the field coils on

TABLE IV

RESISTANCE OF PURE COPPER WIRE

Number B. & S.	Resistance at 75° F.		
	Ohms per 1,000 Feet	Ohms per Mile	Feet per Ohm
0000	.04893	.25835	20,440.
000	.06170	.32577	16,210.
00	.07780	.41079	12,850.
0	.09811	.51802	10,190.
1	.1237	.65314	8,083.
2	.1560	.82368	6,410.
3	.1967	1.0386	5,084.
4	.2480	1.3094	4,031.
5	.3128	1.6516	3,197.
6	.3944	2.0825	2,535.
7	.4973	2.6258	2,011.
8	.6271	3.3111	1,595.
9	.7908	4.1753	1,265.
10	.9972	5.2657	1,003.
11	1.257	6.6369	795.3
12	1.586	8.3741	630.7
13	1.999	10.555	500.1
14	2.526	13.311	396.6
15	3.179	16.785	314.5
16	4.009	21.168	249.4
17	5.055	26.691	197.8
18	6.374	33.655	156.9
19	8.038	42.441	124.4
20	10.14	53.539	98.66
21	12.78	67.479	78.24
22	16.12	85.114	62.05
23	20.32	107.29	49.21
24	25.63	135.53	39.02
25	32.31	170.59	30.95
26	40.75	215.16	24.54
27	51.38	271.29	19.46
28	64.79	342.09	15.43
29	81.70	431.37	12.24
30	103.0	543.84	9.707
31	129.9	685.87	7.698
32	163.8	864.87	6.105
33	206 6	1,090.8	4.841
34	260.5	1,375.5	3.839
35	328.4	1,734.0	3.045
36	414.2	2,187.0	2.414
37	522.2	2,757.3	1.915
38	658.5	3,476.8	1.519
39	830.4	4,384.5	1.204
40	1,047.	5,528.2	.955

a generator. The greatest variation in temperature at all likely to occur, and that will occur but rarely and only in open work, is about 100° F. This will correspond to a change in resistance of about 21 per cent.

The resistances of wires smaller than No. 18 are of no use in practical wiring, but are given for reference, as small wires are used in many pieces of mechanism, such as fan motors, resistance boxes, etc., with which wiremen have to deal, and also in bell and annunciator work.

58. The efficiency of a system of electric wiring is low if the percentage of power that is consumed in heating the wires instead of being conveyed to the lamps or other transforming devices is large. This loss of power (in watts) is equal to the volts *drop* in the line multiplied by the *current* in *amperes*. Wiring specifications usually call for so many volts drop or not more than a certain percentage of drop on the line between the lamps and the center of distribution and between the center of distribution and the point where the wires enter the building or where the dynamo is located.

CALCULATION OF LINE LOSSES DUE TO RESISTANCE

59. We will now calculate the drop on the wires in the factory shown in Fig. 36, using the smallest wires permitted by the Underwriters. The distance from the dynamo D to point A, which is the average distance that the current travels on the No. 6 wire, is 150 feet (allowing for risers to a ceiling 15 feet high). As there must be two wires, the total length of wire is 300 feet or .3 thousand feet.

The resistance of 1,000 feet of No. 6 wire (Table IV) is .3944 ohm; therefore, the resistance of 300 feet of No. 6 wire is $.3 \times .3944 = .11832$ ohm. This line carries 50 amperes. By Ohm's law, the drop is given by the following relation: Drop in line (volts) = current in line $\times$ resistance of line; hence, drop $= 50 \times .118 = 5.9$ volts.

The line from A to B carries current for nine lamps, or 4.5 amperes. Its distance is 140 feet and the resistance of the No. 14 wire is 2.526 ohms per 1,000 feet; hence,

drop $= 4.5 \times \frac{2 \times 140}{1{,}000} \times 2.526 = 3.18$ volts drop on the branch line of No. 14 wire.

The total drop from D to B will then be $5.9 + 3.18 = 9.08$ volts. This is 8.25 per cent. of 110 volts, altogether too much for such a plant as we have been considering.

The reason why such a large loss must not be permitted, in addition to the simple matter of economy of power, is that such a large falling off in voltage will greatly reduce the brightness of the lamps and poor service will result. The cost of power alone, however, is usually a sufficient reason to prohibit such great losses in the wiring.

60. The plant we are considering requires 50 amperes at 110 volts, or 5,500 watts. This, if furnished by a lighting company, will cost between 10 and 20 cents a kilowatt-hour, at the rates ordinarily charged. That will be from $.55 to $1.10 an hour for light. 8.3 per cent. of this is 4.565 cents to 9.13 cents an hour. If the lights are used an average of 2 hours a day 300 days a year, this will amount to from $27.39 to $54.78 a year. Even if the loss were only one-fourth as great, the saving in the cost of light in a year would more than pay for the additional cost of wire.

It is usual to specify a 2-per-cent. drop for such installations as this when the current is to be purchased at fairly high prices, and a 3-per-cent. to 5-per-cent. drop where the current is produced cheaply, as by a dynamo on the premises. Not more than a 5-per-cent. drop should be permitted on short distances, even where very cheap work is desired. This would be accomplished in this case by using No. 4 wire for the feeders and No. 12 for the branch lines. The student may calculate the loss exactly by the use of Table IV.

61. Drop in Arc-Light Wiring.—The loss on the arc lines using No. 10 wire from the point A is found as follows. The resistance of No. 10 wire is about 1 ohm per 1,000 feet.

$$\text{Drop from } A \text{ to lamp No. } 3 = 15\,(\text{amperes}) \times \frac{2 \times 10\,(\text{feet}) \times 1}{1{,}000} = .3 \text{ volt}$$

$$\text{Drop from lamp No. } 2 \text{ to lamp No. } 3 = 10 \times \frac{2 \times 50 \times 1}{1{,}000} = 1 \text{ volt}$$

$$\text{Drop from lamp No. } 1 \text{ to lamp No. } 2 = 5 \times \frac{2 \times 50 \times 1}{1{,}000} = .5 \text{ volt}$$

$$\text{Drop from lamp No. } 4 \text{ to lamp No. } 5 = .5 \text{ volt}$$

$$\text{Drop from } A \text{ to lamp No. } 4 = 10 \times \frac{2 \times 40 \times 1}{1{,}000} = .8$$

$$\begin{aligned}
&\text{Total drop to lamp No. } 1 = .3 + 1 + .5 &&= 1.8 \text{ volts}\\
&\text{Total drop to lamp No. } 2 = .3 + 1 &&= 1.3 \text{ volts}\\
&\text{Total drop to lamp No. } 3 = &&\ .3 \text{ volt}\\
&\text{Total drop to lamp No. } 4 = &&\ .8 \text{ volt}\\
&\text{Total drop to lamp No. } 5 = .8 + .5 &&= 1.3 \text{ volts}
\end{aligned}$$

These slight variations can be permitted on the arc lamps without inconvenience.

62. Size of Wire for Arc Lights.—It should be noted that No. 10 wire is the smallest permitted on this line if the line is protected by but one cut-out. But if the line is divided into two parts, one for lamps Nos. *1*, *2*, and *3* and one for lamps Nos. *4* and *5*, with separate cut-outs for each of these lines, smaller wires may be used, so far as the Underwriters' rules are concerned. Fig. 37 shows the sizes permitted (*a*) with a single branch block and (*b*) with a double branch block.

The wires that have their sizes designated by odd numbers from No. 7 up are not usually manufactured and cannot be purchased except on special order. Therefore, work must be done without using Nos. 7, 9, 11, and 13. The resistances of these sizes, however, are given in the table, as these wires are extensively used in the manufacture of electrical machinery. In tables given later, the above sizes are not given, although in a number of cases they would come nearer the calculated size. In interior wiring it does not, as a rule, pay to be too saving in regard to the sizes of wire, and the nuisance of carrying a large number of sizes of wire in stock more than counterbalances any slight gain there

might be in the copper used on a given job. For this reason, the above odd sizes are not generally used. Moreover, the

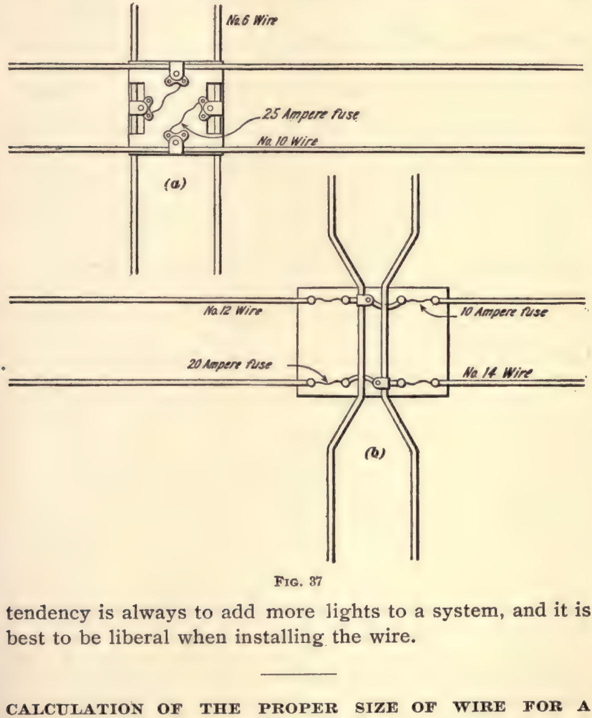


FIG. 37

tendency is always to add more lights to a system, and it is best to be liberal when installing the wire.

CALCULATION OF THE PROPER SIZE OF WIRE FOR A GIVEN LOSS

63. Wiring for 110 Volts, 2 Per Cent. Drop.—We will now calculate the sizes of wires required in the building wired according to Fig. 36 for a loss of 2 per cent. (2 per cent. of 110 = 2.2 volts).

This calculation will be made with a view to making the drop uniform along all the lines; that is, we will make the

volts drop per foot of line as nearly equal as possible in feeders and branches. The proper value of volts drop per foot is found by allowing the desired drop to the most distant group of lamps in the system and distributing this drop uniformly along the lines to the generator.

The average distance from the dynamo to the most distant group of lamps B is $150 + 140 = 290$ feet. This requires 580 lineal feet of wire, or .58 thousand feet, there being two lines. $\frac{2.2 \text{ (volts)}}{.58} = 3.8$ volts per 1,000 feet. 3.8 (volts) $\div$ 50 (amperes) $=$ .076 ohm per 1,000 feet for mains. The nearest wire to this is No. 00, with .078 ohm per 1,000 feet. Using this, the loss on the mains will be $.3 \times .078 \times 50 = 1.17$ volts, leaving $2.2 - 1.17 = 1.03$ volts to be lost in the branch line. The length of the branch is 140 feet (280 or .28 thousand feet double distance) and the drop per 1,000 feet is $\frac{1.03}{.28} = 3.68$ volts. The current in the branch is 4.5 amperes; hence, the allowable resistance per 1,000 feet is $\frac{3.68}{4.5} = .82$ ohm. This would call for a No. 9 wire. In Art. **59** the sizes were No. 6 for the mains and No. 14 for the branch under consideration; consequently, to reduce the drop from 9.08 volts to 2.2 volts these sizes must be increased to No. 00 and No. 9, respectively.

64. Wiring for 220 Volts, 3 Per Cent. Drop.—As a further exercise in calculating the required sizes of wires in terms of resistances per 1,000 feet, let us ascertain the proper sizes of wire to equip the factory with 220-volt lamps, allowing 3 per cent. loss.

As 220-volt lamps are not as efficient as 110-volt lamps, allow 60 watts per 16-candlepower lamp and 3 amperes per enclosed-arc lamp. The circuits for incandescent lamps carry approximately equal loads and are of about the same length, so that it will be sufficient to calculate the size of wire for one circuit only. 10 (lamps) $\times$ 60 (watts per lamp) $\div$ 220 (volts) $=$ 2.73 amperes.

$$
\begin{aligned}
4 \times 2.73 &= 10.92 \text{ amperes for incandescent lamps} \\
5 \times 3.00 &= \underline{15.00} \text{ amperes for arc lamps} \\
& 25.92 \text{ amperes total current}
\end{aligned}
$$

3 per cent. of 220 volts is 6.6 volts. $\frac{6.6}{.58} = 11.38$ volts lost per 1,000 feet; $\frac{11.38}{25.9} = .44$ ohm per 1,000 feet for the mains. The wire with resistance nearest this is No. 6, with .394 ohm per 1,000 feet. Using this size, we have a loss on the mains of $.3 \times .394 \times 25.9 = 3.07$ volts, leaving 3.53 volts to be lost on branch lines.

The size of these branch lines will, therefore, be found as follows: $\frac{3.53}{.28}$ = volts drop per 1,000 feet in branch lines and $\frac{3.53}{.28} \div 2.73 = 4.62$ ohms per 1,000 feet.

Table IV gives 4.009 ohms per 1,000 feet for No. 16 wire, which is smaller than the Underwriters will permit. No. 14 must be used, even though it is larger than necessary as far as the drop is concerned. The loss on the branch line will then be $.28 \times 2.526 \times 2.73 = 1.93$ volts, leaving $6.60 - 1.93 = 4.67$ volts to be lost in the mains, instead of 3.07, as previously calculated. $\frac{4.67}{.3} \div 25.9 = .6$ ohm per 1,000 feet in feeders. No. 8 wire has .627 ohm per 1,000 feet and is nearest the required size.

In 220-volt wiring, where the distances within the building are short, the wireman will usually find that the minimum sizes of wires specified by the Underwriters are large enough to carry the current with less than 2 per cent. loss. In small dwellings wired on the closet system of distribution with 220-volt circuits, it will not be necessary to pay any attention whatever to the drop on inside lines.

65. Center of Distribution.—In making calculations relating to wiring, the distance to be taken is the *average distance* through which the current supplied can be considered as flowing. For example, take a case like that

shown in Fig. 38, where a circuit is run from a distributing point A to a number of lamps B. For the first 100 feet no lamps are connected; we then have, say twelve lamps spread out over 50 feet at the end. In calculating the drop on such a circuit, it is evident that the full length should not be taken, because the whole of the current does not flow through all the line. The current keeps decreasing as each lamp is passed. The center of distribution for the lamps will, therefore, be at C and the average length of wire through which the 6 amperes is carried is $2 \times 125 = 250$ feet. If the lights were bunched at the end of the line, the distance to the center

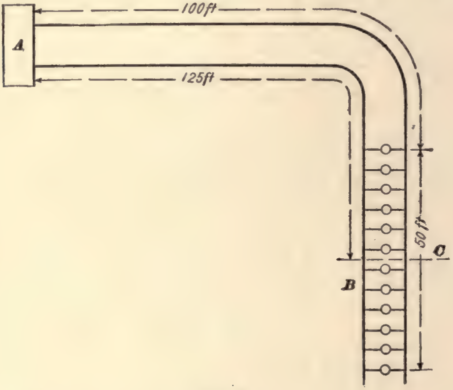
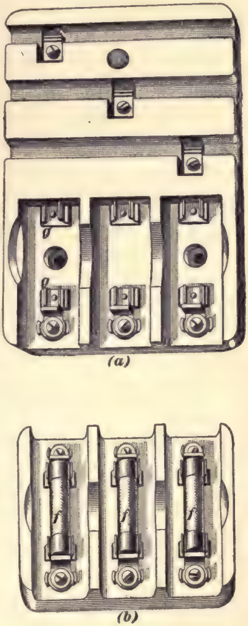


FIG. 38

of distribution would be the same as the length of the line, and the length of wire through which the 6 amperes would flow would be $2 \times 150 = 300$ feet. If the lights were spaced uniformly throughout the whole length of the line, the average distance would be $\frac{150}{2} = 75$ feet and the average length of wire used in making calculations for drop would be 150 feet. By laying out a plan of the wiring, the average distance over which the current is transmitted can usually be determined without much trouble and close enough for practical purposes.

66. Selection of Fittings for 220-Volt Wiring.—In 220-volt wiring, great care must be taken in the selection of fittings. Cut-outs, sockets, and switches designed for 110-volt working and not improved during recent years so as to comply with the more severe requirements of the present day must not be used on higher voltages. Keyless sockets should be used for 220-volt work and the lamps controlled by switches; no rosettes with link fuses should be installed, fuses being placed in approved cut-outs, one of which should be provided for each ten lamps or less. If proper precautions are taken to procure good cut-outs, sockets, and switches, there is no especial difficulty to be encountered in 220-volt work, though the lamps are not as efficient as can be procured for lower voltages.



(a)

(b)

FIG. 39

Fig. 39 (*a*) and (*b*) shows two cut-outs designed especially for 220-volt work. The construction is such as to secure higher insulation and less liability to arcing than with the ordinary 110-volt fittings. Fig. 39 (*a*) is a three-wire branch block shown without the fuses in place. Fig. 39 (*b*) is a three-wire main block with the fuses *f* in their proper position. These fuses are of the enclosed type and are held by clips *g*, *g*, (*a*).

Plug fuses of the cartridge type, Fig. 35, can be used on 220-volt circuits with the cut-outs mounted open. Cut-outs should be provided with barriers or porcelain partitions between the fuses, Fig. 39, so as to prevent arcing between the terminals and accidental short circuits in case any

conductor happens to fall across the cut-out. Open link fuses on 220-volt circuits are only allowable when used on enclosed slate or marble tablet boards.

67. Size of Wire for Three-Wire System.—If it is desired to wire the shop that we have been considering for 110-volt lamps on the Edison three-wire system, the sizes of the main wires required will be the same as for the 220-volt two-wire system, and a third, or neutral, wire must be installed. This is usually placed between the other two; if the wires are put on cleats, three-wire cleats may be used. The neutral wire must not be smaller than will be required for the safe carrying capacity for the current of all the lamps on one side of the circuit. In this case, that current is 25 amperes and the wire must not be smaller than No. 10; it should be larger to prevent unbalancing when lamps are turned off.

68. Unbalancing of Three-Wire System.—The unbalancing of a three-wire system with the three wires of equal size is illustrated in Fig. 40 (*a*) and (*b*). When the system is balanced, as in (*a*), there are 3 amperes in the

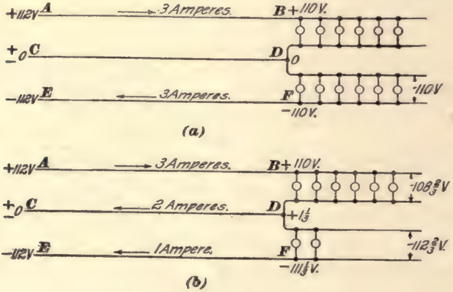


FIG. 40

outside wires and no current in the neutral. Taking the pressure between *A* and *C* or *C* and *E* as 112 volts, and between *B* and *D* or *D* and *F* as 110 volts, there is a drop of 2 volts

in AB and one of 2 volts in EF. The resistance AB, CD, and EF must, therefore, be $\frac{2}{3}$ ohm, in order to give a drop of 2 volts with a current of 3 amperes. If the load becomes unbalanced, as in (*b*), there will be a current of 3 amperes in AB, as before, 2 amperes in CD, and 1 ampere in EF. The drop in AB will be $\frac{2}{3} \times 3 = 2$ volts; in CD, $\frac{2}{3} \times 2 = 1\frac{1}{3}$ volts; in EF, $\frac{2}{3} \times 1 = \frac{2}{3}$ volt. The total drop in the two outside wires will now be $2 + \frac{2}{3} = 2\frac{2}{3}$ volts, and hence the pressure between the outside wires at the end of the line must be $224 - 2\frac{2}{3} = 221\frac{1}{3}$ volts. Taking the upper side of the circuit, we have 3 amperes flowing out through AB and 2 amperes flowing back through CD; the drop on this side must, therefore, be $2 + 1\frac{1}{3} = 3\frac{1}{3}$ volts and the pressure between B and D must be $112 - 3\frac{1}{3} = 108\frac{2}{3}$ volts. The pressure between B and F is $221\frac{1}{3}$ volts; hence, the pressure between D and F must be $221\frac{1}{3} - 108\frac{2}{3} = 112\frac{2}{3}$. The result of the uneven load is, therefore, that the voltage rises in the lightly loaded side and falls on the side having a heavy load. If the neutral wire were smaller, this unbalancing would be greater.

The branch lines of a three-wire system being simple two-wire circuits, they must be calculated for the proper current and drop in the same way as ordinary two-wire circuits.

INTERIOR WIRING
(PART 2)

UNIFORM DROP IN FEEDER LINES

CALCULATING SIZES OF WIRE REQUIRED

1. In installations where there are many sets of feeders running to various departments, it is usual to allow a certain loss in the feeders and a certain other loss in the distribution wires. The drops in all feeders are made equal, and the dynamo is operated at a higher voltage than the lamps will stand, with the intention of losing a definite amount before the lamps are reached. It is important that the voltage at the lamps should never exceed that for which they are intended.

2. Fig. 1 represents a plant, such as a wagon works or furniture factory; only the outlines of the buildings are indicated. The dynamo and switchboard are located at D in the engine room. The various centers of distribution are to be at or near the centers of the various floors, and a separate pair of feeders is to be run to each distribution center. Where elevator shafts are convenient, they are used to run risers to the upper floors. In the case illustrated there are fourteen pairs of feeder wires, each pair being represented by one line in the figure.

A 115-volt dynamo and 110-volt lamps are to be used. A loss of 2 volts is to be allowed in the distribution wires and

a loss of 3 volts in the feeders, irrespective of their length. The figure shows the plan of the feeders on one floor only; the small round dots indicate risers.

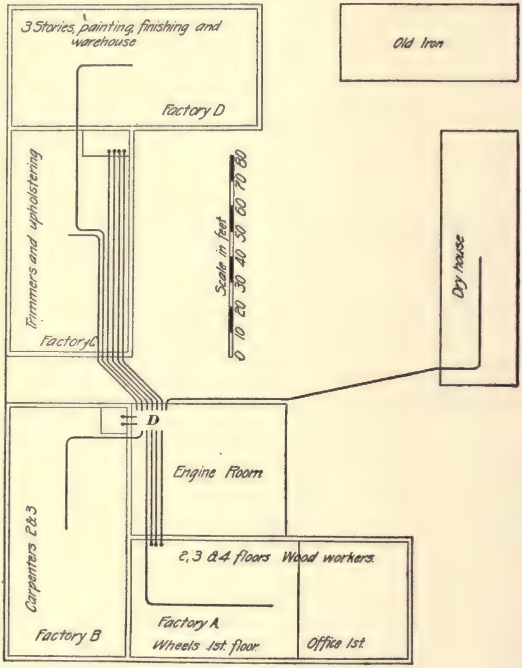


FIG. 1

We will calculate the feeders on one floor only.

	LAMPS	AMPERES	DISTANCE FEET	LENGTH OF WIRE FEET
Shop *A*,	50	25	130	260 (.26 thousand)
Shop *B*,	40	20	75	150 (.15 thousand)
Shop *C*,	40	20	85	170 (.17 thousand)
Shop *D*,	40	20	175	350 (.35 thousand)

The resistance per 1,000 feet of these feeders required to give a drop of 3 volts and the nearest sizes of wires obtainable, are calculated as follows:

Shop A, $\frac{3}{25 \times .26} = .461$, No. 6 has .395 ohm per 1,000 feet

Shop B, $\frac{3}{20 \times .15} = 1.000$, No. 10 has .999 ohm per 1,000 feet

Shop C, $\frac{3}{20 \times .17} = .882$, No. 10 has .999 ohm per 1,000 feet

Shop D, $\frac{3}{20 \times .35} = .429$, No. 6 has .395 ohm per 1,000 feet

This method of calculating required sizes of wires can be applied to any kind of wiring for any practical purpose; but to avoid the necessity of figuring out each case, wiring tables have been prepared by which the proper size can be determined without calculation.

CALCULATION OF WIRE SIZES IN TERMS OF RESISTANCE PER 1,000 FEET

3. Calculations based on resistance per 1,000 feet may be put in the shape of a formula, as follows:

$$r_m = \frac{1{,}000\,e}{2\,D\,I} \qquad (1)$$

in which r_m = resistance of 1,000 feet of wire to be used;
e = drop, in volts;
D = distance, in feet;
I = current, in amperes.

For example, to carry 10 amperes 600 feet ($600 \times 2 = 1{,}200$ feet of wire) with 3 volts drop, the resistance per 1,000 feet will be $r_m = \frac{1{,}000 \times 3}{2 \times 600 \times 10} = .25$ ohm per 1,000 feet. No. 4 wire has about this resistance, as may be seen by consulting a wire table.

4. Wiring Table Giving Distances for Drop of 1 Volt.—In Table I, distances in feet are given in the top

TABLE I

Amperes	Distances in Feet, for Loss of 1 Volt																
	20	25	30	35	40	45	50	60	70	80	90	100	120	140	160	180	200
	Size of Soft-Copper Wire, in B. & S. Gauge																
1														14	14	14	14
1.5												14	14	12	12	12	12
2									14	14	14	14	12	12	12	10	10
3							14	14	12	12	12	12	10	10	10	8	8
4						14	14	12	12	12	10	10	10	8	8	8	8
5				14	14	12	12	12	10	10	10	10	8	8	8	6	6
6			14	12	12	12	12	10	10	10	8	8	8	6	6	6	6
7		14	12	12	12	12	10	10	10	8	8	8	6	6	6	6	5
8		14	12	12	10	10	10	10	8	8	8	8	6	6	6	5	5
9	14	12	12	12	10	10	10	8	8	8	8	6	6	6	5	4	4
10	14	12	12	10	10	10	10	8	8	8	6	6	6	5	5	4	4
12	12	12	10	10	10	8	8	8	6	6	6	6	5	4	4	3	3
14	12	10	10	10	8	8	8	6	6	6	6	5	4	4	3	3	2
16	12	10	10	8	8	8	8	6	6	5	5	5	4	3	3	2	2
18	10	10	8	8	8	8	6	6	6	5	5	4	3	3	2		
20	10	10	8	8	8	6	6	6	5	5	4	4	3	2	2		
25	10	8	8	6	6	6	6	5	4	4	3	3	2				
30	8	8	6	6	6	5	5	4	3	3	2	2					
35	8	6	6	6	5	5	4	3	3	2	2						
40	8	6	6	5	5	4	4	3	2	2							
45	6	6	5	5	4	4	3	2	2								
50	6	6	5	4	4	3	3	2									
55	6	5	4	4	3	3	2	2									
60	6	5	4	3	3	2	2										
65	6	5	4	3	3	2	2										
70	5	4	3	3	2	2											
75	5	4	3	2	2												
80	5	4	3	2	2												
90	4	3	2	2													
100	4	3	2														

horizontal line. Beneath these distances are columns containing numbers that designate the proper size of wire to use to obtain a drop of 1 volt when the wire carries the current given in the corresponding line in the left-hand column.

If it is desired, for example, to find the size of wire necessary to get a loss of not more than 1 volt with 20 amperes, and a distance of 140 feet (i. e., two wires, 140 feet long), we look under 140 and to the right of 20 and find the figure 2. No. 2 wire will be required. If it is desired to find the wire required for a loss of 2 volts with 20 amperes and a distance of 140 feet, we may divide the distance by the loss in volts and use the table as before; i. e., under 70 and to the right of 20 is found 5. No. 5 is the proper wire. Or, we may use the distance given and divide the current by the number of volts; i. e., under 140 and to the right of 10 is found 5. The table is sufficiently accurate for all practical purposes, but where very great exactness is desired, it is better to calculate the lines. For the smaller sizes in this table, the nearest even sizes of wire above No. 6 are given because the odd sizes are not ordinarily used.

CALCULATION OF WIRES IN TERMS OF CIRCULAR MILS

5. In the Underwriters' table of safe carrying capacities, the wires are listed both by number (B. & S. gauge) and by **circular mils.** Cables having no B. & S. gauge number are listed by circular mils only. Large cables of any desired cross-section in circular mils are made by all the leading manufacturers of insulated wires.

It is often more convenient to calculate the size of wires or cables in terms of circular mils than in terms of resistance per 1,000 feet; and calculations in terms of circular mils are applicable to wires or cables of any size or shape.

A round wire 1 mil in diameter has a cross-section of **1 circular mil.** A copper wire 1 mil ($\frac{1}{1000}$ inch) in diameter and 1 foot long (**1 mil-foot**) has a resistance of 10.8 ohms; or, *1 mil-foot of copper has 10.8 ohms resistance at 75° F.*

A wire 2 mils in diameter has a section of 4 circular mils (sometimes abbreviated C. M. or cir. mils); 3 mils in diameter, 9 circular mils; 4 mils, 16 circular mils; 5 mils, 25 circular mils; x mils, x^2 circular mils. *The circular mils cross-section of any round wire is equal to the square of its diameter in mils.* The circular mils of any conductor of other shape is equal to its area in *square mils* multiplied by 1.273 or divided by .7854. For instance, the circular mils of No. 0000 wire (diam. = 460 mils) = 460^2 = 211,600 circular mils, while a bar of copper $\frac{1}{4}$ inch by $\frac{1}{2}$ inch (250 mils by 500 mils) has a section of $250 \times 500 = 125{,}000$ square mils, or $250 \times 500 \times 1.273 = 159{,}125$ circular mils.

6. If the length, in feet, of a wire is known and also its area, in circular mils, the resistance may at once be determined by the formula

$$R = \frac{10.8\,L}{\text{cir. mils}} \qquad (2)$$

In this formula, L must be the total length of wire in feet.

Also, since the drop e in a circuit is equal to the current $I \times$ resistance R, we have

$$\text{drop } e = \frac{10.8\,LI}{\text{cir. mils}} \qquad (3)$$

or if the drop is given and we are required to find the size of wire to give this drop, we may put formula **3** in the form

$$\text{circular mils} = \frac{10.8\,L\,I}{e} \qquad (4)$$

In these formulas, L is the total length of the circuit, i. e., the distance to the lamps and back again. If the distance to the lamps, one way, is called D, we may put formula **4** in the form

$$\text{circular mils} = \frac{21.6\,D\,I}{e} \qquad (5)$$

This last formula will generally be found as useful as any that can be given for interior-wiring calculations. It will be well to commit it to memory, because one does not always have a wiring table at hand when calculations are to

be made and, besides, calculations have often to be made that are beyond the range of the tables. It can be applied to any two-wire system or to the three-wire system, as illustrated by the following examples:

EXAMPLE 1.—By means of formula **5**, calculate the size of wire necessary to supply eighty 16-candlepower lamps situated at a distance of 200 feet from the center of distribution. The allowable drop is to be 3 volts.

SOLUTION.—We have $D = 200$ and $e = 3$. Each 16-c. p. lamp will take about $\frac{1}{2}$ ampere; hence, $I = 40$.

$$\text{cir. mils} = \frac{21.6 \times 200 \times 40}{3} = 57{,}600$$

or between No. 2 and No. 3 B. & S. No. 2 wire would likely be used. Ans.

EXAMPLE 2.—Calculate the size of wire necessary to supply one hundred lamps on a 110–220-volt three-wire system. The distance from the center of distribution to the lamps is 250 feet and the drop on each side of the system is not to exceed 3 volts. The lights are supposed to be balanced, fifty lamps on each side.

SOLUTION.—The simplest method of solving this problem is to treat it as if it were a two-wire system and use formula **5**. Each pair of lamps will take $\frac{1}{2}$ ampere; hence, the current in the outside wires, when all the lamps are burning, will be $\frac{100}{4} = 25$ amperes instead of $\frac{100}{2} = 50$ amperes, as it would have been if a two-wire system had been used. The allowable drop on each side of the circuit is 3 volts; hence, the total drop in the outside wires will be 6 volts. We have, then,

$$\text{cir. mils} = \frac{21.6 \times 250 \times 25}{6} = 22{,}500$$

A No. 6 wire will be large enough and also would likely be installed for the neutral. Ans.

The same method may be used for a 220–440-volt three-wire system, except that in estimating the current, allow about .3 ampere for each pair of lamps instead of .5 ampere, as in the previous case.

7. Estimation of Current Required by Lamps.—As mentioned, it is customary in estimating the current taken by lamps to allow about $\frac{1}{2}$ ampere for each 110-volt 16-candlepower lamp, and others according to the values given. The most accurate way, however, is to figure the current from

the total watts supplied and the known voltage. For a two-wire system the current is as follows:

$$\text{Current} = \frac{\text{number of lamps} \times \text{watts per lamp}}{\text{voltage at lamps}} \qquad \textbf{(6)}$$

For a balanced three-wire system

$$\text{Current} = \frac{\text{number of lamps} \times \text{watts per lamp}}{\text{voltage between outside wires at lamps}} \qquad \textbf{(7)}$$

These formulas are general and apply to lamps of any efficiency.

CALCULATIONS FOR ALTERNATING CURRENT

8. For ordinary two- or three-wire work with alternating current, calculations may be made in the same way as for direct current. When wiring is done in conduit, the two wires must be run in the same conduit, otherwise inductive effects will greatly reduce the voltage at the lamps. With ordinary open wiring, the induced counter E. M. F. is not usually large enough to produce any noticeable effects, especially when the load consists wholly of lamps. When lamps are operated on two-phase or three-phase alternating-current systems, the different circuits are connected to different phases so as to balance the load, and as far as interior wiring is concerned, the lighting circuits are single-phase and are calculated in the same way as ordinary two-wire circuits.

OTHER FORMS OF WIRING TABLES

9. Before leaving the subject of wire calculations, attention is called to the fact that there are methods of arranging wiring tables other than that given in Table I, for it is easy to produce several arrangements of the same matter. The table that one is most accustomed to use seems the simplest. Tables calculated for incandescent lamps, instead of for amperes, are useless for general work and should not be used for calculating wiring for lamps, unless it is known that the efficiency of the lamps on which the table is based is the same as that of the lamps to be used.

Table II is very convenient because it gives the distance exactly corresponding to the required drop. To use it, divide

TABLE II

Size of Wire, B. & S. Gauge	Amperes																								
	1	2	3	4	5	6	7	8	9	10	12	15	18	20	25	30	35	40	45	55	65	75	85	95	100
	Distance, in Feet, Producing a Drop of 1 Volt for Given Currents and Given Sizes of Wire																								
18	75.2	37.6	25.1	18.8	15.0																				
16	120.0	60.0	40.0	30.0	24.0	20.0																			
14	190.0	95.0	63.3	47.5	38.0	31.7	27.1	23.8	21.1	19.0	15.8	12.7													
12	302.0	151.0	101.0	75.5	60.4	50.3	43.1	37.7	33.6	30.2	25.2	20.2	16.8	15.1											
10	480.0	240.0	160.0	120.0	96.0	80.0	68.6	60.0	53.3	48.0	40.0	32.0	26.7	24.0	19.2	16.0	13.7								
8	764.0	382.0	255.0	191.0	153.0	127.0	109.0	95.5	84.9	76.4	63.7	51.0	42.5	38.3	30.6	25.5	21.8	19.1	17.0						
6	1,215.0	607.0	405.0	304.0	243.0	202.0	174.0	152.0	135.0	121.0	101.0	81.0	67.5	60.8	48.6	40.5	34.7	30.4	27.0	22.1					
5	1,533.0	766.0	511.0	383.0	307.0	255.0	219.0	192.0	170.0	153.0	128.0	102.0	85.0	76.6	61.3	51.1	43.8	38.4	34.1	27.8	23.6	20.4			
4	1,933.0	966.0	644.0	483.0	387.0	322.0	276.0	242.0	215.0	193.0	161.0	129.0	107.0	96.7	77.3	64.4	55.1	48.3	43.0	35.1	29.7	25.8	22.7		
3	2,437.0	1,219.0	812.0	609.0	487.0	406.0	348.0	305.0	271.0	244.0	203.0	162.0	135.0	122.0	97.4	81.1	69.6	60.9	54.0	44.3	37.5	32.5	28.7	25.7	24.4
2			1,024.0	768.0	615.0	512.0	439.0	384.0	341.0	307.0	257.0	205.0	171.0	154.0	123.0	102.0	87.9	76.9	68.3	55.9	47.3	41.0	36.2	32.4	30.7
1			1,291.0	969.0	775.0	646.0	554.0	484.0	431.0	387.0	323.0	258.0	215.0	194.0	155.0	129.0	111.0	96.9	86.0	70.3	59.6	51.7	45.0	40.8	38.7
0				1,222.0	978.0	815.0	698.0	611.0	543.0	489.0	407.0	326.0	272.0	245.0	195.0	163.0	140.0	122.0	109.0	88.7	75.2	65.1	57.5	51.4	48.9
00					1,232.0	1,027.0	880.0	770.0	685.0	616.0	513.0	410.0	342.0	308.0	246.0	205.0	176.0	154.0	137.0	112.0	94.8	82.0	72.5	64.8	61.6
000						1,295.0	1,110.0	971.0	863.0	777.0	648.0	518.0	432.0	388.0	311.0	259.0	222.0	194.0	173.0	141.0	119.0	104.0	91.4	81.7	77.7
0000							1,400.0	1,225.0	1,089.0	980.0	817.0	653.0	544.0	490.0	392.0	326.0	280.0	245.0	218.0	178.0	151.0	131.0	115.0	103.0	98.0

the number of amperes transmitted by the number of volts drop desired. Find the nearest number to this result in the line of amperes; below this find the distance, in feet, most nearly corresponding to the given distance; to the left of this, in the column of wire sizes, is given the number of the required wire.

For example, to find the size of wire to transmit 15 amperes 140 feet with 3 volts loss, divide 15 by 3 and find the quotient 5 in the line of amperes. In the column below, we find the nearest distance 153, and to the left of this the size of wire required, No. 8.

10. Probably the most convenient of all methods of calculation, after one is accustomed to using it, is the graphic method, in which amperes and distances are laid off at right angles to one another, and the wires corresponding to different values of these quantities, for a loss of 1 volt, are represented by curved lines. Figs. 2 and 3 are diagrams of this kind. Notice that every wire curve is dotted for a short distance for currents larger than the maximum allowed by the Underwriters' rules for that size of wire. In determining the size of wire from these diagrams, do not use the dotted portions of the curves. If a point should come near one of the dotted sections, use the next larger size of wire.

To use such a diagram, find the point where the lines representing amperes and given distance intersect, and take the wire indicated by the wire line nearest this point. Unless the wire line is very close, take the larger wire of the two lines on each side of the intersection point.

For example, to find the wire required for 7 volts loss in a distance of 125 feet, with 21 amperes, divide 21 by 7, which gives 3; the line of 3 amperes intersects the line of 125 feet about midway between the lines representing No. 10 and No. 12 wire; hence, the larger size of wire, No. 10, would be used.

11. In calculating the sizes of wires for 52-, 104-, 220-, or 250-volt work, or for any intermediate voltage, it must be borne in mind that lamps burning on lower voltages than 110 take more current, and those burning on higher voltages take less current. An ampere per lamp for 52-volt lamps,

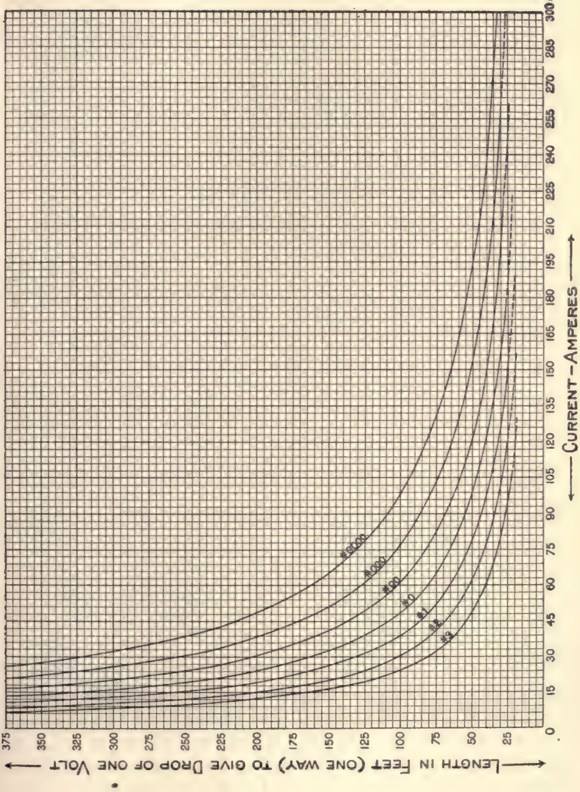

Current—Amperes
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300
Length in Feet (One Way) to Give Drop of One Volt
25 50 75 100 125 150 175 200 225 250 275 300 325 350 375
#0000
#000
#00
#0
#1
#2
#3

Fig. 2

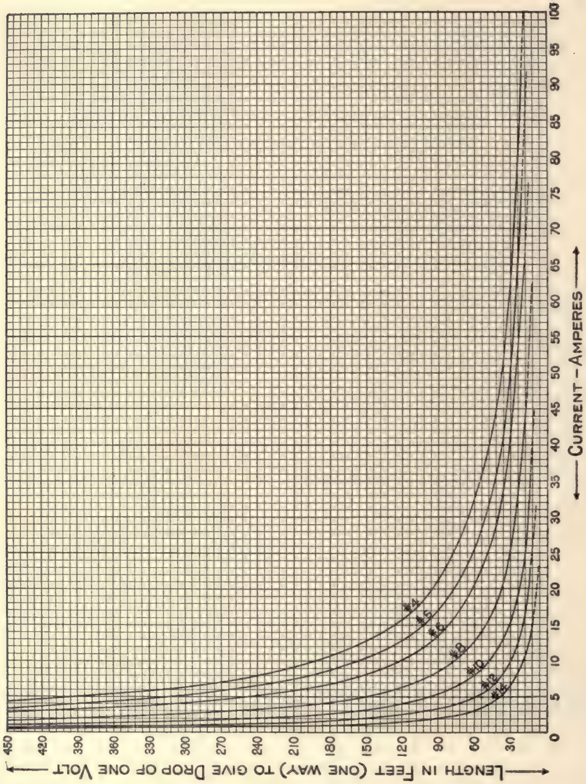

CURRENT - AMPERES
LENGTH IN FEET (ONE WAY) TO GIVE DROP OF ONE VOLT
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
#4
#5
#6
#8
#10
#12
#14

FIG. 3

½ ampere per lamp for 104- or 110-volt lamps, and .3 ampere per lamp for 220-volt lamps is a safe basis for calculations where good lamps are used. Also, it must be remembered that "per cent. drop" and "volts drop" are very different things, as set down in Table III.

The figures given in the table represent the actual drop, in volts, for the line voltage at the top of each column, with the percentages of drop given in the left-hand column. For example, a drop of 5 per cent. on a voltage of 150 would give 7.5 volts.

TABLE III

Per Cent. Drop	Line Voltages					
	52	104	110	150	220	250
1	.52	1.04	1.1	1.5	2.2	2.5
2	1.04	2.08	2.2	3.0	4.4	5.0
3	1.56	3.12	3.3	4.5	6.6	7.5
5	2.60	5.20	5.5	7.5	11.0	12.5
7	3.64	7.28	7.7	10.5	15.4	17.5
10	5.20	10.40	11.0	15.0	22.0	25.0
15	7.80	15.60	16.5	22.5	33.0	37.5

FUSE PROTECTION FOR CONDUCTORS IN PARALLEL

12. It is sometimes desirable to run two or more small wires in parallel, instead of one large wire or cable, for convenience in handling the wires, to obtain a certain carrying capacity with the use of less copper, to use material that happens to be at hand, or for other reasons. When two or more wires are run thus and are connected together at their ends, separate fuses must be placed in series with each wire, and not one fuse for all the wires in parallel.

Fig. 4 (*a*) and (*b*) illustrates the correct and the incorrect methods of connecting such cables. Multiple conductors of this kind may sometimes be used to advantage in overhauling or remodeling old work, where the wires originally installed are too small, and in wiring an old building by the

use of molding, where large wires cannot be handled without defacing the walls.

For convenience in comparing the conductivities of wires, Table IV is given. As an illustration, it is seen from the table that instead of a single No. 2 wire we might use a No. 4 and a No. 6; two No. 5; four No. 8; etc. Of course, nothing smaller than No. 14 can be used for interior wiring.

The conductivity is directly proportional to the total cross-section of all the conductors in parallel, and the total resistance is inversely proportional to the total cross-section.

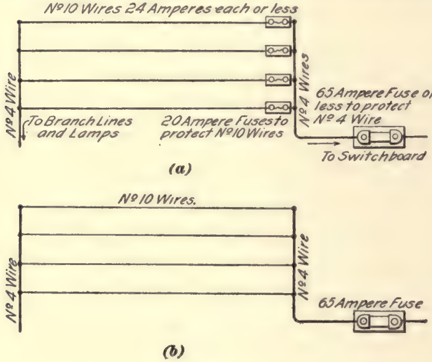


Fig. 4

13. Circuits of several wires in parallel are sometimes run where a large drop in voltage is not objectionable, but where a single wire small enough to produce that drop will not carry the current safely. Two or more small wires will safely carry more current than one large wire of equivalent cross-section, because two small wires have a greater surface area from which the heat can escape than has one wire of twice the cross-section. For instance, suppose that it is desired to run wires in molding to secure a drop of 4 volts with 65 amperes over a distance of 100 feet. Calculating the required size of wire by means of Table II, we see that No. 5 will give the required drop. But No. 5 rubber-covered

TABLE IV

EQUIVALENT CROSS-SECTION OF WIRES

Number of Wire, B. & S. Gauge	Equivalent Cross-Section, in Terms of Smaller Wires								
0000	00 + 1	2— 0	4— 3	8— 6	16— 9	32—12	64—15	128—18	1 + 2 + 2
000	0 + 2	2— 1	4— 4	8— 7	16—10	32—13	64—16	128—19	2 + 3 + 3
00	1 + 3	2— 2	4— 5	8— 8	16—11	32—14	64—17	128—20	3 + 4 + 4
0	2 + 4	2— 3	4— 6	8— 9	16—12	32—15	64—18		4 + 5 + 5
1	3 + 5	2— 4	4— 7	8—10	16—13	32—16	64—19		5 + 6 + 6
2	4 + 6	2— 5	4— 8	8—11	16—14	32—17	64—20		6 + 7 + 7
3	5 + 7	2— 6	4— 9	8—12	16—15	32—18			7 + 8 + 8
4	6 + 8	2— 7	4—10	8—13	16—16	32—19			8 + 9 + 9
5	7 + 9	2— 8	4—11	8—14	16—17	32—20			9 + 10 + 10
6	8 + 10	2— 9	4—12	8—15	16—18				10 + 11 + 11
8	10 + 12	2—11	4—14	8—17	16—20				
10	12 + 14	2—13	4—16	8—19					
12	14 + 16	2—15	4—18	8—20					
14	16 + 18	2—17	4—20						
16	18 + 20	2—19							

wire will safely carry only 54 amperes, while 65 amperes is to be transmitted. By using two No. 8 wires, which are equivalent in cross-section to one No. 5, we can safely carry the current with the specified drop. If the current were still greater, we could use one No. 8 and two No. 10 wires with about the same results. However, such arrangements to secure a drop are only used in emergencies or under special conditions, and are usually only temporary expedients.

14. Calculation of Wires in Parallel.—If a number of wires are to be used in parallel to do the work of a single large wire, i. e., to carry a certain current a given distance with a specified drop, the combined cross-section of the smaller wires must equal the cross-section that the large wire would have. Suppose, for example, that a wireman at a distance from a supply house has on hand a large amount of No. 12 wire, but no larger wire, and that he desires to carry a current of 40 amperes, 150 feet (one way) with 3 volts loss. How many No. 12 wires should be connected in parallel to secure the result? Using formula **5**, $I = 40$, $D = 150$, and $e = 3$; hence, circular mils $= \frac{21.6 \times 150 \times 40}{3} = 43{,}200$.

The cross-section of No. 12 wire is 6,530 circular mils, approximately; hence, to make up a cross-section of 43,200 circular mils, $\frac{43{,}200}{6{,}530} = 6.6$ No. 12 wires in parallel would be required. In this case, therefore, it would be necessary to use seven No. 12 wires, as this is the whole number nearest to 6.6.

Take another example. In an old building, wired with too much drop, it is desired to reenforce the mains so as to reduce the drop to 2 volts. A circuit of No. 8 wire carrying 20 amperes a distance of 150 feet is to be reenforced. What size of wire should be used?

The cross-section necessary to carry 20 amperes, 150 feet with a drop of 2 volts is, from formula **5**,

$$\text{circular mils} = \frac{21.6 \times 150 \times 20}{2} = 32{,}400$$

No. 8 wire has a cross-section of 16,510 circular mils; hence, the cross-section to be added is 32,400 − 16,510 = 15,890. Another No. 8 wire (16,510 circular mils) connected in parallel with the No. 8 wire already installed, will give slightly more than the required cross-section and would therefore be used.

EXAMPLES FOR PRACTICE

1. Determine, by means of formula **5**, the size of wire required to carry 30 amperes a distance of 150 feet (one way) with a drop of 3 volts. Ans. No. 5 B. & S.

2. If a circuit 200 feet long (single distance) carries 25 amperes and is of No. 6 B. & S. wire, what will be the drop in volts? Ans. 4.1 volts

3. If a circuit of No. 10 B. & S. wire carries 20 amperes a distance of 200 feet (single distance) what size of wire must be connected in parallel with the existing wire to limit the drop to 2 volts? Ans. No. 5 B. & S.

4. A current of 40 amperes is to be carried 300 feet (single distance) with a drop of 3 volts. Assuming that No. 10 B. & S. is the only size of wire available, how many wires must be connected in parallel to carry the current with the specified drop? Ans. 8 wires

WIRING IN DAMP PLACES

15. Where wiring is done in damp places, special precautions must be taken and special rules observed. The following Underwriters' rules apply to this work:

Wires—

In damp places, or buildings especially liable to moisture, or acid, or other fumes liable to injure the wires or their insulation:

a. Must have an approved insulating covering.

For protection against water, rubber insulation must be used. For protection against corrosive vapors, either weather-proof or rubber insulation must be used.

b. Must be rigidly supported on non-combustible, non-absorptive insulators that separate the wire at least 1 inch from the surface wired over, and wires must be kept apart at least $2\frac{1}{2}$ inches for voltages up to 300 and 4 inches for higher voltages.

Rigid supporting requires under ordinary conditions, where wiring over flat surfaces, supports at least every $4\frac{1}{2}$ feet. If the wires are liable to be disturbed, the distance

between supports should be shortened. In buildings of mill construction, mains of No. 8 B. & S. gauge wire or over, where not liable to be disturbed, may be separated about 6 inches, and run from timber to timber, not breaking around, and may be supported at each timber only.

Sockets—

a. In rooms where inflammable gases may exist, the incandescent lamp and socket must be enclosed in a vapor-tight globe and supported on a pipe hanger, wired with approved rubber-covered wire soldered directly to the circuit.

b. In damp or wet places or over specially inflammable stuff, waterproof sockets must be used.

Waterproof sockets should be hung by separate *stranded*, rubber-covered wires, not smaller than No. 14 B. & S. gauge, which should preferably be twisted together when the pendant is over 3 feet long. These wires should be soldered direct to the circuit wires, but supported independently of them.

Fig. 5 shows a waterproof globe for use where inflammable gases may exist. In wiring damp cellars, it is especially desirable to have the lamps divided among several small circuits, so that the blowing of a fuse will not put out many lamps. In such work, rosettes should never be used, but the drop wires should be soldered to, but not supported by, the line wires, and the joints should be thoroughly wrapped with insulating tape. The cut-outs should be placed outside the cellars, in a dry place, if possible, otherwise they should be placed in waterproof boxes. It should be noted that, in damp places, particular attention must be paid to the character of the insulation. There must be a clear air space around the wires so that there will be no chance for moisture to accumulate and cause short circuits.

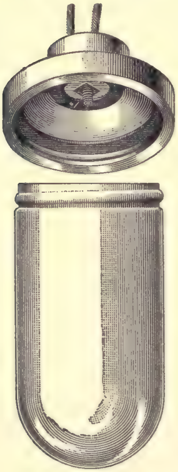


FIG. 5

CONCEALED WIRING

16. Concealed wiring is usually installed according to one or more of the following methods: *concealed knob and tube*, *conduit*, and *molding*. Concealed knob-and-tube work has been used in the past more than either of the other methods; it is the cheapest of the three and is quite safe if properly installed. The local rules governing wiring in some of the larger cities have recently prohibited this class of work, but it is allowed by the Underwriters' rules. Conduit work is expensive and the knob-and-tube plan affords a means of concealing wires at comparatively small cost and, while it is unquestionably not as safe or as permanent as the conduit method, there is no reason why it should not be safe and satisfactory if the work is done as it should be. It is much used for dwelling houses or similar places where the cost must be kept down. Conduit wiring involves the installation of a complete piping system in addition to the wiring system so that the cost becomes very great. It represents the best method of wiring and is now used on all important work where the highest degree of safety and permanence is required. It is the only class of wiring to be considered for fireproof office buildings, hotels, or similar structures. The use of molding work is confined almost entirely to old buildings where the wires cannot be concealed and where it is necessary to run them in woodwork to match the woodwork in the rooms. Very often concealed knob-and-tube work can be combined with conduit work to advantage, flexible conduits being very useful where wires must be fished for short distances or where they have to be run in places where there is not room enough for supporting them on porcelain insulators. The concealed knob-and-tube method does not afford the wiring mechanical protection, and consequently is not suited to places where the conductors are liable to be disturbed or come in contact

with other objects. However, in non-fireproof buildings where the wires can be run between the joists there is little danger of their being disturbed, and wires well supported on knobs have amply high insulation. The class of work to be used in any given case will depend on the character of the building to be wired, the allowable cost, and on the local regulations, if any, governing the wiring of buildings.

CONCEALED KNOB-AND-TUBE WORK

17. The most common way of concealing wires in non-fireproof buildings is to run them through the joists between the floors and ceilings and through studding partitions, and to insulate them by means of porcelain knobs and tubes, as shown in Fig. 6. The holes should not be closer together than is allowed by the Underwriters' rules, and the tubes should fit tightly in the holes. When the holes are not horizontal, but are bored from above or below obliquely, the tubes should be put in with their heads on the high side, so that they cannot fall or slide out; and when tubes are placed so that there is any strain on them, their heads must be so placed that the tubes cannot slip. Holes should be bored of such a size that the tubes can be inserted by driving lightly. Do not make the holes too small or there will be danger of breaking the tubes. Holes must be bored sufficiently far away from

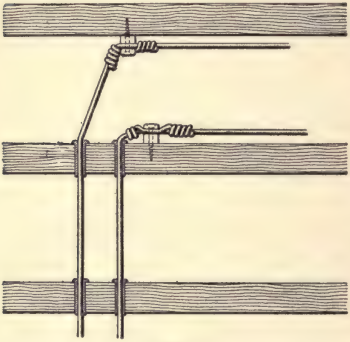


FIG. 6

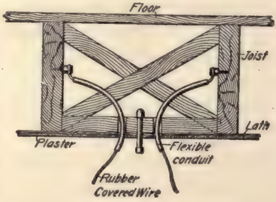
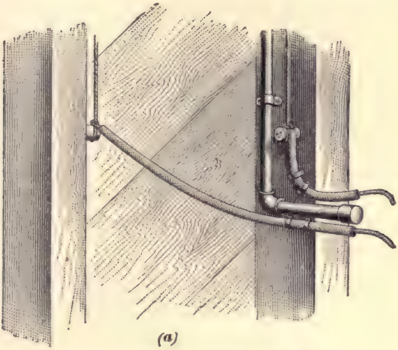


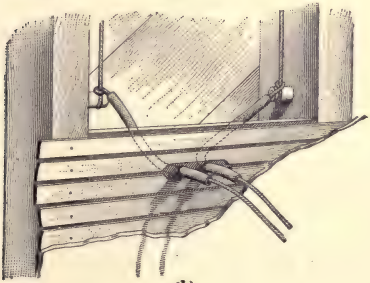
FIG. 7

the floors and ceilings to be out of reach of nails that may be driven into the joists after the work is concealed. Bushings must be long enough to reach all the way through the joists, with $\frac{1}{2}$-inch projection.

18. Where wires come through the plaster to outlets or cut-outs, they must be protected by flexible insulating tubes



(a)



(b)

FIG. 8

that will preclude all possibility of contact between the wires and other objects. Careless work is often done at outlets, with the result that a job that is otherwise well put up will show poor insulation. The same outlets are very often used

both for gas and electricity, and if the wires are not well protected where brought out, a ground on the gas-pipe may result.

Fig. 7 shows the method of bringing out a ceiling outlet with knob-and-tube work. The flexible conduit used to protect the wires projects as far as, or slightly beyond, the end of the pipe and runs back as far as the porcelain support next to the outlet. Fig. 8 (*a*) and (*b*) shows two methods of bringing out side-wall outlets, (*a*) being a combination gas and electric outlet and (*b*) a plain electric outlet. The latter shows a board nailed across between the studs to support the fixture. In both cases the flexible conduit extends back to the insulators, as required by rule (*d*).

19. For running wires parallel to joists, knobs are generally used because they make it possible to keep the wires well separated. The following rules apply to this kind of work:

Wires—

For concealed knob-and-tube work:

a. Must have an approved rubber insulating covering.

b. Must be rigidly supported on non-combustible, non-absorptive insulators that separate the wire at least 1 inch from the surface wired over, and must be kept at least 5 inches apart, and when possible, should be run singly on separate timbers or studding. Must be separated from contact with the walls, floor timbers, and partitions through which they may pass by non-combustible, non-absorptive insulating tubes, such as glass or porcelain.

Rigid supporting requires under ordinary conditions, where wiring along flat surfaces, supports at least every $4\frac{1}{2}$ feet. If the wires are liable to be disturbed, the distance between supports should be shortened.

c. When, in a concealed knob-and-tube system, it is impracticable to place any circuit on non-combustible supports of glass or porcelain, approved metal conduit, or approved armored cable must be used except that if the difference of potential

between the wires is not over 300 volts, and if the wires are not exposed to moisture, they may be fished on the loop system if separately incased throughout in continuous lengths of approved flexible tubing.

In general, when conduit of any kind is used in connection with concealed knob-and-tube work, it must be installed in accordance with the rules governing the use of conduit as given later. In most interior wiring for lighting work, the pressure between any pair of wires will not exceed 300 volts, so that in cases where it is necessary to pass wires through spaces where porcelain supports cannot be used on account of lack of space or because they must be run through some place that is inaccessible, it is allowable to fish the wires through provided they are separately incased in flexible tubing. The loop system referred to in rule (*c*) is explained in connection with conduit wiring. It should be particularly

FIG. 9

noted that wires must not be run through flexible tubing in cases where dampness is present. The armored cable referred to in rule (*c*) would seldom be required in connection with knob-and-tube work in a new building where everything is accessible; but in an old building where there are objections to tearing up floors to insert wires, it may often be used to advantage, particularly if the wires are liable to be exposed to mechanical injury.

Fig. 9 shows an *armored twin cable;* the wire is rubber-covered and over the heavy insulation is wound a steel strip that interlocks so as to form a continuous protection. It is possible to use armored cable for the complete wiring of a building, in which case outlet boxes, etc. are provided as in conduit wiring, described later. The conduit system is, however, preferable because the wires can be withdrawn. Where armored cable is used in damp places it must have a lead

sheath between the insulation and the armor. Protected flexible cord, of the same style, is a very convenient article to use in wiring offices, banks, etc., where small conductors must be carried behind desks or fastened to iron or cabinet work, and in many other places where ordinary cords will not do and will not be permitted.

The following rule governs the arrangement of the wire at outlets when it is run on the concealed knob-and-tube plan:

> *d.* Must at all outlets, except where conduit is used, be protected by approved flexible insulating tubing, extending in continuous lengths from the last porcelain support to at least 1 inch beyond the outlet. In case of combination fixtures, the tubes must extend at least flush with the outer end of the gas cap.

It should be particularly noted that in concealed knob-and-tube work, or in fact in any kind of concealed wiring, the wire must be rubber-covered. Weather-proof or fireproof and weather-proof wires are prohibited for concealed work. The calculations for concealed wiring are the same as for open work; but it must be remembered that rubber-covered wires are not allowed to carry as much current as weather-proof wires, as shown by the Underwriters' table of carrying capacities.

20. Use of Cabinets and Panel Boards.—For concealed work, the **closet, or cabinet,** system of distribution is now universally used. In it the mains are run to *cabinets* or *panel boards* set in the wall, and the lines running to the lamps are distributed from these. Many styles of these panel boards are manufactured, and the kind used will depend largely on the size and allowable cost of the installation. For the cheaper class of work, the cut-outs may be grouped together and placed in a cabinet formed in the wall. This cabinet should be neatly lined with $\frac{1}{8}$-inch asbestos secured in place by tacks and shellaced. Where the wires pass into and out of the sides or bottom, they should be bushed with porcelain tubes. A neat glass or asbestos-lined door should be provided. A cabinet made in this way is

inexpensive and safe, though slate- or marble-lined cabinets are much better and their use is strongly recommended. Slate- or marble-lined cabinets should always be provided with a job of conduit wiring.

Fig. 10 will give an idea as to the essential parts of a panel board. In this case, the wires are run in conduits. The box is mounted in the wall and consists of two compartments, the inner compartment containing the panel board, and the outer one, or *gutter*, as it is sometimes called. All boxes are not provided with this gutter, but the best ones are, as it gives a convenient space in which to arrange the wires in case they should not come to the box in the best order for connecting up. The box is made of slate or marble slabs. The trim around the door covers the gutter; it should be put up with screws so that it may be removed if necessary.

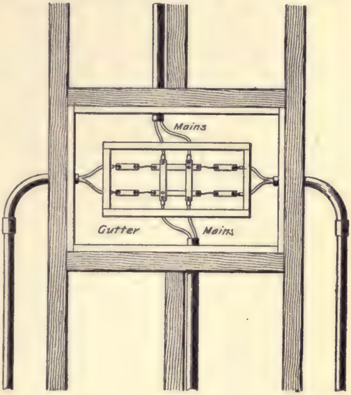


Fig. 10

The mains usually pass through the panels vertically and are connected to bars from which the various lamp circuits branch out sidewise. Fuses are inserted in each side of each circuit, and switches are also provided in some cases, though sometimes the panel board carries fuses only in case the switches are located near the lamps rather than at the center of distribution represented by the fuse cabinet.

Fig. 11 shows a panel board equipped with double-pole knife switches *a* and enclosed fuses *b*. Eighteen branch circuits are accommodated and the three-wire vertical mains are attached to the copper bars *c*, *c*, *c*; the mains enter at the bottom, being conducted to the board through the large

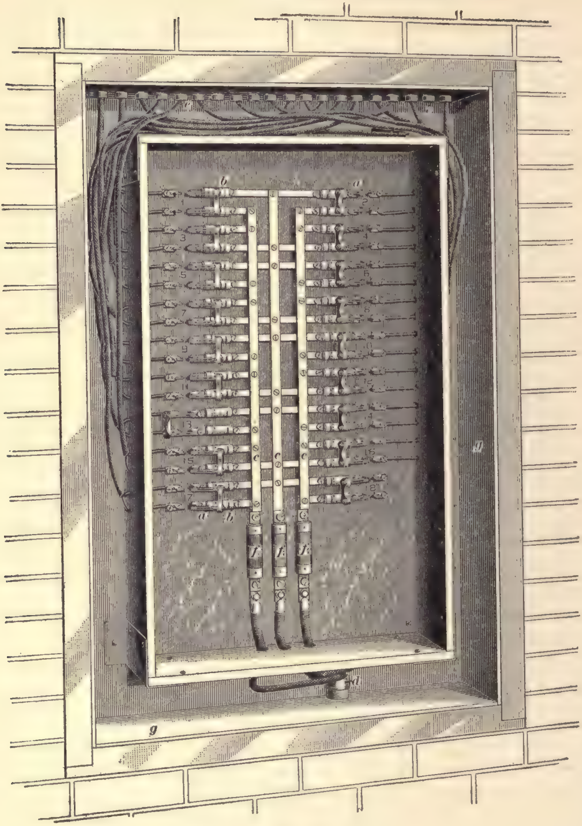


FIG. 11

conduit *d* that projects a short distance into the gutter, or distribution compartment. The casing and door are removed in order to show the method of bringing the wires around to the various switches. The outgoing circuits are carried through the conduits *e* that enter at the top, each conduit containing a twin wire. The panel board constitutes the back of the cabinet and the sides and ends are of $\frac{1}{2}$-inch slate. The main fuses are of the enclosed type and are

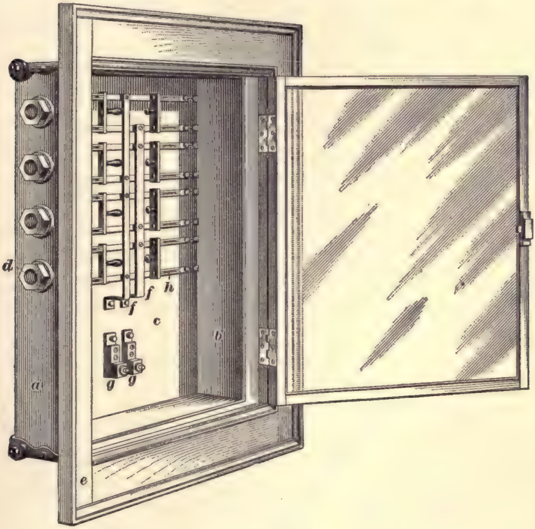


FIG. 12

shown at *f*. The lining *g* of the gutter is of $\frac{1}{16}$-inch enameled iron or $\frac{1}{4}$-inch slate or marble. With knob-and-tube work the gutter may be lined with $\frac{1}{8}$-inch asbestos firmly tacked in place, though it is always better to use slate or marble lining.

21. Instead of building a box of slate or marble pieces, iron or steel boxes lined with slate or marble are much used. Fig. 12 shows a cabinet of this kind ready to be set

into the wall and connected up. It is made of a sheet-steel box *a*, whose sides and top are lined inside with $\frac{1}{4}$-inch slate slabs *b*. The panel board *c* constitutes the back of the box. In the figure the openings *d* for the branch circuits are arranged to take conduits. The two-wire vertical mains are connected to terminals *g*, *g* and, through the main fuses, to the bars *f*, *f*. Each branch circuit is provided with fuse terminals and a knife switch *h*.

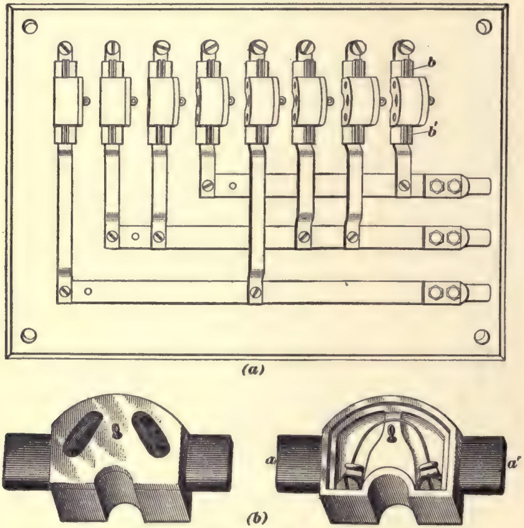


Fig. 13

Fig. 13 (*a*) shows a style of panel board that uses a special kind of fuse holder which serves the purpose of a switch when it is desired to disconnect any circuit. Panel boards using combination fuse holders have been adopted quite largely, for they have one advantage in that the holder may be entirely removed from the board when the fuse is being replaced, or a reserve holder may be put in instead of the one

removed. Fig. 13 (*b*) shows one of these holders. It is held in place by the clips *b*, *b′*, shown in (*a*), that receive the blades *a*, *a′*. Link fuses are here used; they are allowable because the fuse holder is used in a fireproof cabinet and not in an open cut-out. Fig. 14 shows a plain two-wire board for four branch circuits; it is equipped with Edison fuse plugs and has no switches. The foregoing will give a general idea as to the construction of these boards. They are made in all sorts of combinations and, in fact, are usually made to order for any given job. In large wiring systems, the design of the

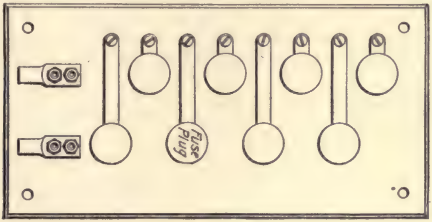


Fig. 14

cut-out closets, or cabinets, is a matter of great importance, and the location of these closets is equally important; they should be placed in a position where they can be readily reached.

Cabinets must be provided with a substantial door; if glass is used it must not be less than $\frac{3}{16}$ inch thick nor more than 1 foot wide. At least 2 inches clear space must be allowed between the fuses and the glass. The door must close against a rabbet, so as to be dust-tight, and bushings through which the wire enters must fit the box tightly. Wires should completely fill the holes in the bushings; if necessary, the wire should be built up with tape so as to keep out dust.

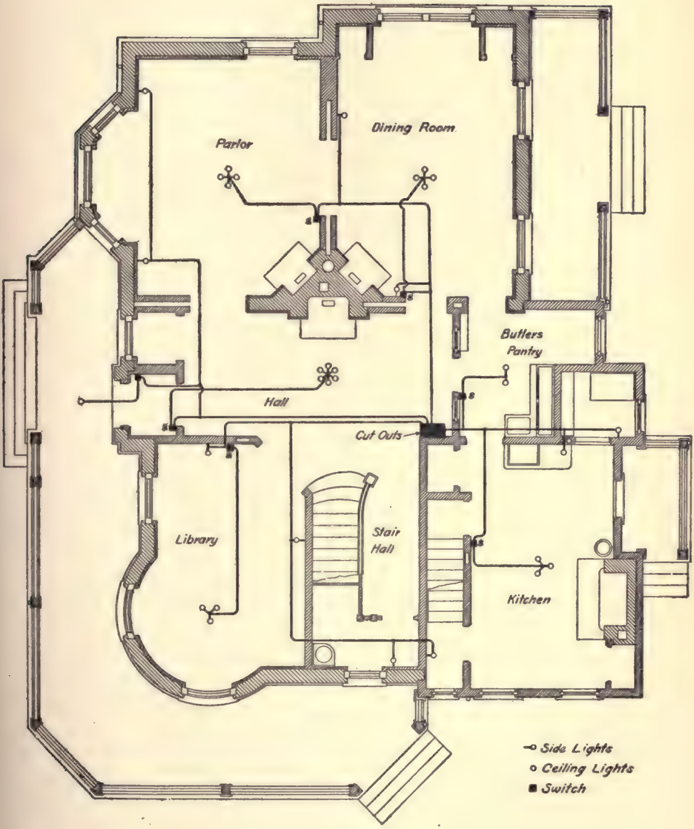
WIRING A DWELLING HOUSE

22. In laying out the wiring for a dwelling house, the first thing to do is to locate the cut-out cabinets. In many dwelling houses, only one cabinet may be necessary, but in houses designed to be occupied by more than one tenant, a cut-out cabinet should be installed for each

tenant. In large houses, it is often convenient to have a cut-out cabinet on each floor, with vertical mains running through them from the top to the bottom of the house. If only one distributing point is used, it should be either in the cellar or attic and risers should run to the different floors. If it is known that the wires are to enter the building in the cellar, the distributing center should be located there; if the wires enter in the attic, the distributing point should be located there. This assumes that vertical risers are run from the distributing center to feed the various floors. In case a single pair of vertical mains is used with the circuits branching off on each floor, the mains may be run from the top to the bottom of the house and the current supplied from either end.

No matter what arrangement is adopted for distributing the current, the distributing centers, or cut-out cabinets, should be in or near a partition that is located so as to make the running of risers easy. They should also be as near the center of the building as possible and on an inside wall, so as to guard against dampness.

23. Figs. 15 and 16 show two floors of a typical dwelling. The distributing points are located in the hallway near the center of the house, because such location is central and easy to get at. The various branch circuits on the plans are indicated by single lines, although each line represents two wires. The wiring is supposed to be done on the ordinary concealed knob-and-tube system and no circuit carries more than ten lights. Switches are placed on the side walls, as shown at *s*. The switch for controlling the hall lights should be placed at some convenient point near the door, so that the lights may be turned on when entering the building. It is sometimes convenient to have another switch at the head of the stairs for controlling the hall light, so that the light may be turned on or off from either above or below. This requires the use of three-point switches, the necessary connections for which will be explained later. In the plans, double-pole switches are indicated; single-pole switches,



Dining Room
Parlor
Butlers Pantry
Hall
Cut Outs
Library
Stair Hall
Kitchen
Side Lights
Ceiling Lights
Switch

FIG. 15

which are cheaper to install, may, however, be used when not over 660 watts are controlled.

24. Laying Out Circuits.—In laying out the various branch circuits, the first thing to do is to locate the lights on the plan and then group these lights for the different circuits, so that there will not be more than ten or twelve lights on each one. After this is done the lines may be marked; in doing this, due regard should be given to the direction in which the joists run, so that the wire may be put in with as little boring and cutting as possible. Run parallel to the beams wherever it can be done, even if it does take a little more wire. The best time to wire the building is after the floorbeams and studding are in place, but before any lathing or plastering has been done. In Fig. 15, four circuits are provided, all terminating in the cut-out cabinet in the hall, where they are attached to the vertical mains. For the second floor, Fig. 16, three circuits are sufficient. No. 14 wire is used for all these circuits. It will be found that No. 14 wire (the smallest that the Underwriters allow) is large enough for any of the branch circuits met with in ordinary house-wiring work. The number of lights per circuit is small and the distances short, so that No. 14 will carry the current with but a small drop in voltage.

25. The Mains.—If vertical mains are used, the current that they will carry will be less at one end than at the other, because current is taken off at the different floors. It is usually advisable, however, to make the mains the same size all through an ordinary house, because it costs but little more and enables the current to be supplied from either end. In large buildings, where it would not pay to do this, it is customary to install a number of risers feeding different sections of the building and running to a common distributing point, usually located in the basement. The mains must, of course, be designed to carry the current in accordance with the Underwriters' requirements or to limit the drop to the allowable amount if the wire required by the Underwriters will give too much drop. Suppose that the

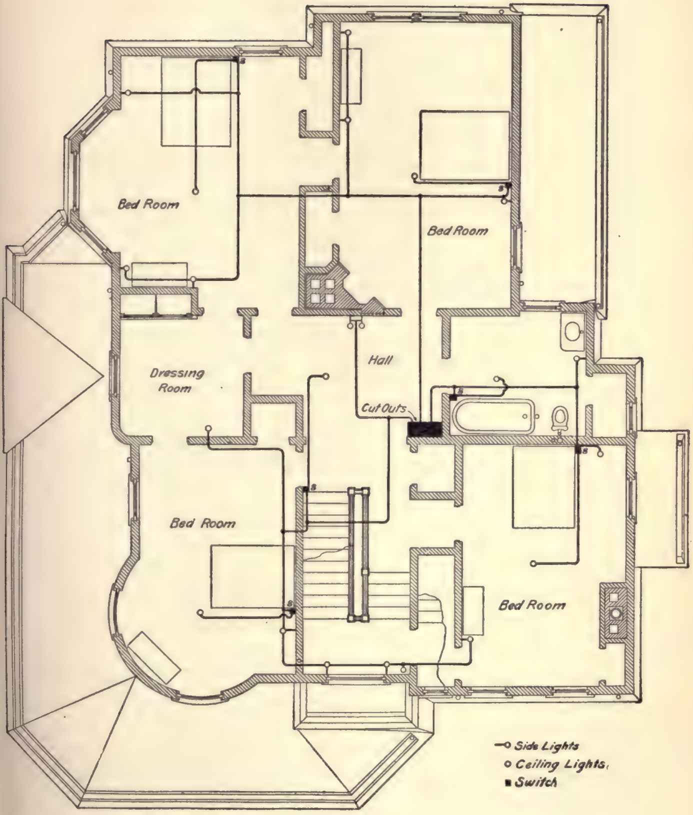

Bed Room
Bed Room
Hall
Dressing Room
Cut Outs
Bed Room
Bed Room
Side Lights
Ceiling Lights
Switch

FIG. 16

house under consideration has a total of 60 lamps. The current in the mains will then be 30 amperes, and at least a No. 8 wire will be required to satisfy the Underwriters' requirements.

By referring to Table II, it is found that No. 8 wire will carry 30 amperes a distance of 25.5 feet with a drop of 1 volt. For a building of this kind, the drop from the point where the current enters the building to the lamps should not exceed 2 to 2.5 volts. The drop in the branch circuits is very small, but it would be advisable to put in No. 6 mains, as the difference in first cost will be but little. It is the usual practice to make the mains of liberal cross-section. For a house of this size No. 4 would often be used, although it does not need to be as large as this so far as drop is concerned.

26. Main Switch, Cut-Out, and Meter.—At a convenient point near the place where the wires enter the building, a main cut-out and switch must be placed, as required by the Underwriters. The cut-out should be placed nearest the point of entry, the switch next to it, and the meter last. Never permit the meter to be installed between the switch and the cut-out, as in that case it may register a small amount each day, even if the switch is open. If a knife-blade switch is used at the entrance to the building, it should be placed so that when opened it will not tend to fall closed of its own accord. It is also advisable to place it in an asbestos-lined box provided with a lined door.

The best arrangement of the wires for the meter will depend to some extent on the type of meter used. In a great many cases, however, the wires enter the left-hand side of the meter and pass out at the right. Fig. 17 represents a typical arrangement of main fuses, switch, and meter.

Most recording electric meters consist of a small electric motor, the revolving part of which turns on jeweled bearings and is connected to a train of gears and dials. The motor is governed by means of retarding devices, so that it runs at a speed accurately proportional to the load. Some

meters read in ampere-hours, but most of those now installed read in watt-hours and are provided with two coils, one of which is connected in series with the circuit, like an ammeter, and the other across the circuit, like a voltmeter. The current in the first is, therefore, equal to the current supplied, and the current in the second is proportional to the voltage. The force tending to drive the motor is, therefore, proportional to the product of the amperes and volts, i. e., to the watts. The small third wire running into the meter, Fig. 17, is to supply current to the potential coil. With ampere-hour meters, a series coil only is used, and the speed of the meter is proportional to the current and not to the watts.

The voltage of a lighting system is, however, practically constant, so that the watt-hours may be obtained by multiplying the ampere-hours by the voltage without serious

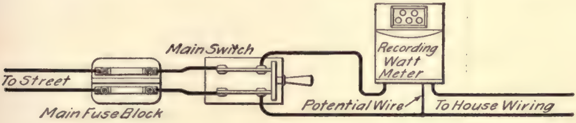


FIG. 17

error. Reliable meters are made for all voltages and systems and for alternating or direct currents. They are accurate to within 98 per cent. on ordinary loads, but are liable to be out as much as 5 per cent. on small loads, and most meters will take a very small load without turning at all. However, they are seldom operated under such conditions.

27. In new buildings, it is often not known what system of electric lighting will be used when the wiring is finished. Owners also desire quite frequently to be able to avail themselves of any advantage in price that may be brought about by competition between different systems. It is therefore desirable that each new house shall be wired in such a manner that light may be secured from any system in use; that is, from 110- or 220-volt two- or three-wire systems.

The following typical specifications cover all the main points necessary for such a piece of work in an ordinary dwelling house.

Other details, such as the location of additional switches, the use of particular kinds of cut-outs, etc., may be added to these specifications if desired. The specifications cover only the concealed work.

Specifications for Concealed Electric-Light Wiring

For 110- or 220-Volt Systems

Distribution Cabinet

A distribution cabinet is to be located on some inside wall, in a readily accessible place, on the second floor or the attic, as near the center of the building as possible.

The cabinet must be lined with slate $\frac{1}{4}$ inch thick and fitted with a door covered on the inside with slate $\frac{1}{4}$ inch thick.

Circuits

From this cabinet separate circuits must be run to the outlets in such a manner that not more than ten 16-candlepower incandescent lamps shall be placed on any circuit. Wherever the number of lamps is not marked on the plans or otherwise specified as greater than here required, pendants shall be considered as intended to carry four lamps each and brackets one lamp each.

Fuses

All fuses must be located on a panel board placed in the distribution cabinet. The panel boards must be of slate at least $\frac{3}{4}$ inch thick and be provided with terminals designed for enclosed fuses. Both sides of all lines must be fused and the fuses must be of a type suitable for use on 220 volts and capable of interrupting the arc due to a 220-volt short circuit.

Wires

All circuits running from the distribution center must be of No. 14 B. & S., or larger,

rubber-covered copper wire of a make accepted by the National Board of Fire Underwriters.

Mains

From the distribution cabinet to the attic, and also to the basement, a pair of mains must be run, the size of which will depend on the total number of lights in the house, as follows:

17 lamps, or less . . .	No. 14 or larger
18 to 24 lamps, or less . . .	No. 12 or larger
25 to 33 lamps, or less . . .	No. 10 or larger
34 to 46 lamps, or less . . .	No. 8 or larger
47 to 65 lamps, or less . . .	No. 6 or larger

If the house contains more than sixty-five lamps, it is advisable to have more than one distribution center and pair of mains.

Extra Wire

A third wire, two sizes smaller than these mains, must also be run from the attic to the basement, through the distribution cabinet, to make possible the use of the three-wire system.

Manner of Fastening Wires

Wires running parallel to joists must be fastened on porcelain knobs, placed on different timbers, and kept as far apart as possible. In passing through joists, floors, and other woodwork, the holes must be bushed with porcelain tubes, which must extend at least ½ inch through the wood and be so arranged that their weight will tend to keep them in place rather than to cause them to slip out.

Space Between Wires

All wires must be kept at least 5 inches away from one another, from gas or water pipes, iron beams, bell or annunciator wires, speaking tubes, furnace pipes, and other conducting materials, except at the distribution cabinet and fixture outlets. Where wires cannot be kept this far apart they must be run in conduits.

Outlets

Flexible insuiating conduits must be used at outlets. Special care must be taken to insulate from the gas pipe at outlets.

Running Along Brick or Stone Walls

Brick and stone walls must be avoided wherever possible. Wherever wires pass along them, they must be incased in approved conduits.

Main-Line Cut-Out and Fuse

There must be supplied and installed by the contractor a main-line cut-out and a quick-break switch, both double-pole, to be located in the attic at the end of the feeder lines: These devices must be approved by the Underwriters as capable of breaking the current for the total number of lamps wired, at either 110 or 220 volts. Knife switches, if used, must be so connected that they open downwards and the blades must be "dead" when the switch is open, and must be mounted in an asbestos or slate-lined box provided with a similarly lined door.

Inspection, Certificate, and Payment

The contractor must notify the Underwriters' Association of the progress of his work in time to have a thorough inspection made (2 days before work is concealed at least). He must secure a certificate from that Association stating that the work is suitable for use on 110- or 220-volt service, two- or three-wire systems, before any payments shall be made to him.

SWITCHES

28. Switches located at various points on the walls of rooms are a great convenience and should be installed on all first-class jobs of any magnitude. The single-pole snap switch (for not more than 660 watts) is the simplest and cheapest. It opens one side of the circuit only. Next in frequency of its use is the double-pole snap switch for larger chandeliers or groups of lights. In addition to these, there are a number of special uses of switches to allow lamps to be controlled from two or more points.

29. Control of Lamps From Two Points.—Fig. 18 (*a*) and (*b*) shows a switching arrangement for controlling

the light or group of lights L from two points A and B. This scheme is used principally in halls where it is desired to control the light from either up or down stairs. It requires two three-point switches S, S', which are here shown as simple lever switches. There are a number of different makes of switches for this purpose, but the principle of all is the same, though the mechanical details may differ. By comparing the diagrams with whatever make of switch he may have to install, the wireman should have no

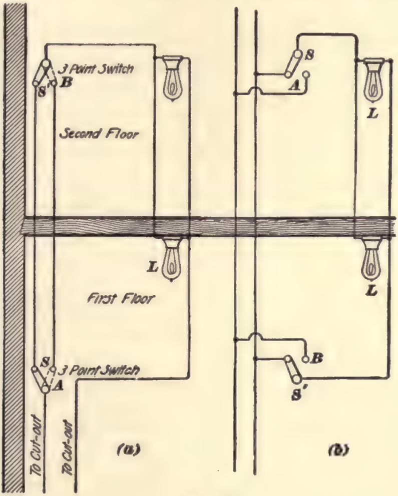


FIG. 18

difficulty in getting the connections correct. By examining the connections, it is seen that the lamps L may be lighted or extinguished from either point. Either method of connection (a) or (b) may be used, and the one that will be most convenient in any given case will depend to some extent on the general layout of the wiring.

A modification of this arrangement is shown in Fig. 19 (a) and (b). In this case, one of the three-way switches is

replaced by a three-way socket. By using a three-way socket on the fixture in connection with a three-way switch on the side wall, a lamp may be turned on or off either at the socket or at the switch. Both schemes of connection (*a*) and (*b*) accomplish the same result, and the one that is most convenient in any case will depend considerably on the location of the supply mains.

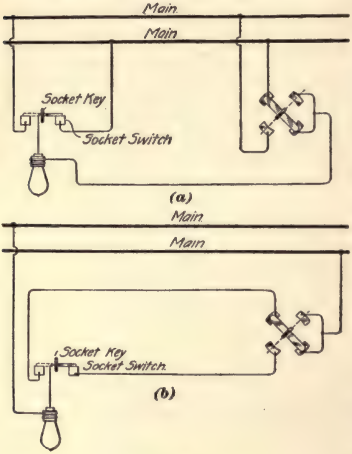


Fig. 19

30. Control of Lights From Three or More Points.—To control lights from three stations, as indicated in Fig. 20, it is necessary to use two three-point switches *A*, *C* for the end stations and a four-point switch *B* for the middle station. When *B* is in the position shown,

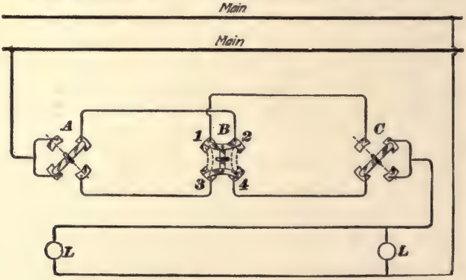


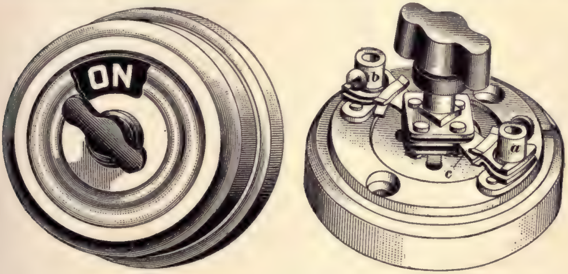
Fig. 20

points *1* and *2* and points *3* and *4* are connected together. When the switch is turned, these connections are broken and

points *1* and *3*, *2* and *4* are connected. By tracing out the path of the current, the student will see that the lights may be turned on and off from any station independently of the position of the switches at the other stations. By cutting in a four-point switch for each additional station this scheme can be extended to any number of stations desired, and is often used for stairways in apartment houses.

31. Electrolier Switches.—These switches usually have three or four points and are used in connection with electroliers to enable a part or the whole of the lights to be operated as desired; sometimes they are mounted in the electrolier itself. They are made in a variety of forms and the connections necessary are, as a rule, easily understood by an examination of the switch that it is proposed to use.

32. Snap Switches.—Fig. 21 shows a typical single-pole snap switch; the same type of switch is made double-pole; also, three-point and four-point for the control of lamps from two or more stations. The wires come through the porcelain base of the switch and are held in posts *a b*, which



(a) (b)

FIG. 21

also carry the switch contacts. When the switch is closed, the rotary cross-piece *c* makes connection between posts *a b*, thus closing the circuit. A double-pole switch has two pieces *c* and four contact posts. It is desirable to have snap switches provided with an indicating dial, as shown in Fig. 21 (*a*),

unless the position of the switch handle shows clearly whether the switch is "on" or "off." Indicators are specially useful when a number of switches are mounted together. Snap switches are comparatively inexpensive but they project from the wall and do not make as neat a job as flush switches, which set into boxes placed in the wall. With conduit wiring, flush switches are nearly always used and, even with concealed knob-and-tube wiring they are used on jobs where a neat appearance is desired.

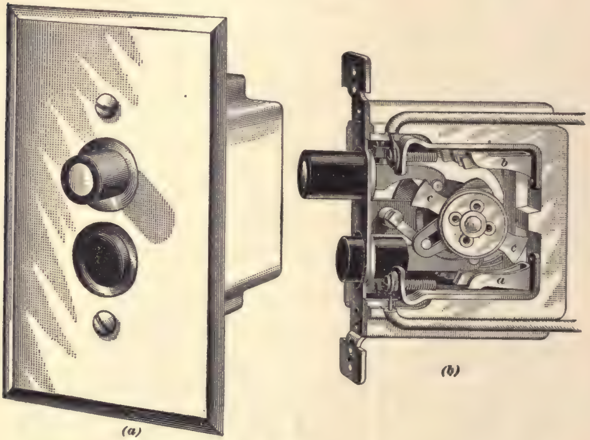


FIG. 22

Fig. 22 (*a*) shows the general appearance of a flush switch of the push-button type. The mechanism (*b*) is double pole and when the light button is pushed in, crosspiece *c c* swings around and makes contact between clips *a* and *b*. In order to prevent arcing at the contacts, all switches are constructed so that they will open or close with a quick positive motion.

When switches are mounted flush, an iron box must be provided in which to place them. This box may be either of cast iron or stamped steel and must completely enclose

the switch, thus providing a protection in addition to the usual porcelain base that carries the switch mechanism.

Fig. 23 shows a stamped-steel switch box. The cover, which carries the switch, is attached to the box by means of screws passing through slotted holes. This allows the switch to be placed square even though the box may have been mounted slightly crooked or displaced slightly during the installation of the wires. Steel boxes can be obtained with any combination of inlet holes so that they can be suited to wires coming in from any direction. In many cases the boxes are made so that pieces of metal can be knocked out, thus making holes wherever desired. There should be no holes in the boxes other than those used for bringing in the conduits.

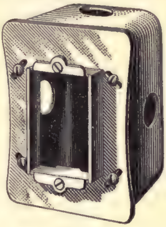


Fig. 23

FIXTURES

33. The selection of suitable **fixtures** and the proper wiring of them are important matters. The wireman should not be satisfied to put up any fixtures that may be furnished. He should examine them and test them himself. The following rules should be observed:

Fixtures—

a. Must, when supported from the gas piping or any grounded metal work of a building, be insulated from such piping or metal work by means of approved insulating joints placed as closely as possible to the ceiling.

Gas outlet pipes must be protected above the insulating joint by approved insulating tubing, and where outlet tubes are used they must be of sufficient length to extend below the insulating joint, and must be so secured that they will not be pushed back when the canopy is put in place.

Where canopies are placed against plaster walls or ceilings in fireproof buildings, or against metal walls or ceilings or plaster walls or ceilings on metallic lathing in any class of buildings, they must be thoroughly and permanently insulated from such walls or ceilings.

b. Must have all burrs, or fins, removed before the conductors are drawn into the fixture.

c. Must be tested for contacts between conductors and fixture, for short circuits, and for ground connections before it is connected to its supply conductors.

34. Rule (*c*) is important. In wiring up fixtures, it is an easy matter for the fixture wire to become grounded on the shell and all fixtures should be thoroughly tested with a magneto before they are connected to the circuit. It is much easier to locate the faults before the fixtures are put up than it is after. In connecting fixtures to the line wires, all joints should be soldered and thoroughly taped so that there will be no danger of grounding or short-circuiting when the canopy is pushed up in place. Particular attention should be given to the connecting of the lamp sockets; this is a part of the fixture wiring that is often slighted and causes many short circuits and grounds. Great care should be taken to see that the sockets are good, and also that they are strong enough to bear the weight of shades. Faulty sockets are more likely to cause trouble on fixtures than on drop cords, for the socket itself is always grounded on the fixture, and if either wire becomes grounded on the socket shell, it is in consequence grounded on the fixture.

INSULATING JOINTS

35. The **insulating joint** is the most important electrical fitting used in fixture work; joints are made for all possible combinations. Fig. 24 shows a very good style; piece *a* screws on to the gas pipe and *b* to the fixture. The parts are separated by insulating material *e*, and the outside of the joint is covered with molded insulation *d*. The gas pipe above the joint must be covered by an insulating tube, as required by rule (*a*),

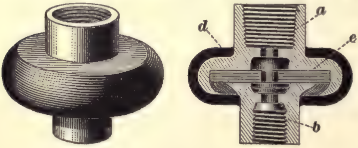


FIG. 24

Art. **33,** and after the outlet wires have been soldered to the fixture wires the joints should be carefully taped and the wire bunched in below the insulating joint so as not to interfere with the canopy. In connecting insulating joints to the gas pipe, red lead or white lead should not be used; asphaltum or some similar insulating compound is preferable. Insulating joints should be tested before being used and canopy insulators should be installed as required by rule (*a*). In ordinary dwelling houses, where the ceilings are plastered on wood lath, or in other non-fireproof buildings where there is no metal work about the ceilings or walls, it is not necessary to use canopy insulators. The

Fig. 25

canopy is the brass cup-shaped piece used at the top of fixtures to cover the joint. It is in contact with the fixture; hence, it is important that it be insulated from metal ceilings, or else all the benefits derived from an insulating joint will be lost. Fig. 25 shows a canopy insulator, which is simply an insulating ring placed between the canopy and the ceiling.

36. The E. M. F. between the wires used on electric fixtures must never exceed 300 volts and the wires must not be smaller than No. 18 B. & S. gauge. If wires are secured to the outside of fixtures, as is sometimes the case when old gas fixtures are fitted with electric light, they must be fastened so that there will be no danger of the insulation being damaged by the pressure of the fastenings or by the motion of the fixture. The wire used for fixtures must be rubber-covered, and may be solid or stranded. Special wire is made for this purpose.

Fixtures should be firmly fastened in place. Combination fixtures are supported by the gas pipe but plain electric fixtures are generally fastened by screwing them into a wall or ceiling plate, or crowfoot. This method is satisfactory if a solid wood backing is provided and the fixture is not very heavy. In the case of heavy electroliers, the pipe should extend through the ceiling and be firmly fastened to the

joists or other secure support. In case outlet boxes are used, as with conduit work, the gas pipe extends through the box and carries the fixture if a combination fixture is used. For plain electric fixtures, the outlet boxes are provided

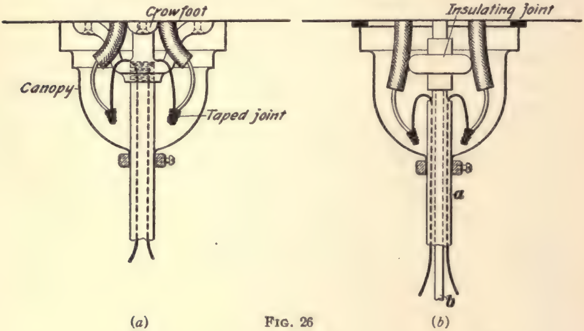


Fig. 26

with a threaded projection, which holds the fixture, the outlet box serving as a base or crowfoot. Fig. 26 (*a*) shows the arrangement of a plain electric fixture and a combination fixture connected to outlets wired on the concealed knob-and-tube plan. The flexible tubing projects through the ceiling, as shown, and is connected to the fixture wires. In the combination fixture (*b*), the fixture wires are run between the outer shell *a* and the gas pipe *b*.

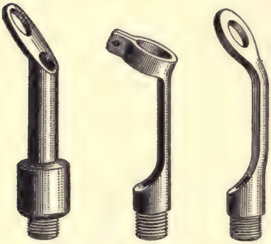


Fig. 27

When old fixtures are to be wired, they must be taken down and supplied with insulating joints. Sockets may be attached to old gas fixtures by means of spars Fig. 27, that fasten to the fixtures at the gas burners.

LOCATION AND DISTRIBUTION OF LAMPS

37. The character of the lamps to be used and their location is a matter that must be determined in each case by the purpose for which the lamps are installed. For signs and decorative work, they are used solely to attract attention or to produce ornamentation. In interior lighting, their purpose is to illuminate other objects either close at hand, as with desk lamps, or at a somewhat greater distance. Where illumination is the sole requirement, the lamps should be placed where they cannot be seen, but where they will throw their light on the object to be illuminated, as on the stage of a theater. In general work, however, it is not possible to place the lamps in this manner, but they should be placed where they will not be too conspicuous. When they must be in view, the lamps should be surrounded by shades that will diffuse the light and take away the glare. Frosted globes are of assistance in many places, but it is better to have the light diffused by a shade. Shadows should be avoided as much as possible.

38. Chandeliers are usually relied on for general illumination. They should be hung high to get the best effects, and should never be as low as the level of the eye of a person standing. Borders or rows of lights placed on the ceiling near the walls give very good illumination without hurting the eyes. To get the best illumination with the smallest number of lamps, the walls and ceilings should be finished in light colors or in white and should be kept clean. It is cheaper to retint ceilings than to burn many lamps; this is especially true of stores, where much illumination is a necessity. Walls papered in dark colors and woodwork of dark, rich wood make it almost impossible to light a room brilliantly.

On account of the great influence of the color of walls, height of ceilings, etc. it is impossible to give other than very approximate figures for the amount of light required for illuminating a given room. For rooms requiring ordinary

illumination and having ceilings about 10 feet high, about .25 to .29 candlepower per square foot should be sufficient. For rooms with high ceilings .45 to .5 candlepower per square foot should be allowed, and for very brilliant lighting in ballrooms or similar places, the allowance may be as high as 1 candlepower per square foot. Of course, these figures are for cases where the whole room is to be generally illuminated; when the light is used locally, as at desks or reading tables, it may not be necessary to have the room generally illuminated and the allowance per square foot might be much less than that indicated by the above figures.

CONDUIT WIRING

EARLY CONDUIT SYSTEMS

39. A number of years ago, before there were uniform rules governing the installation of wires to make them safe, it was a common practice to use, for electric lighting, wires wound with cotton thread saturated with paraffin. These wires were fastened with wooden cleats nailed against the walls and ceilings. Signal and bell wires are still sometimes put up in this way. The first step in the direction of improvement was limiting the number of incandescent lamps allowed on a given size of wire. The next was the substitution of "weather-proof" or "Underwriters'" wire for the paraffin-covered "office wire." Later came the porcelain cleat, which was not in general use before 1892.

The manner of installing wire in concealed work has undergone a similar evolution. At first wires were pulled through holes in the joists and installed without any protection other than their insulating covering; sometimes even two wires were pulled through the same hole, but this was not long tolerated. Progress came along two distinctly different lines: one that of insulating the wire by the use of knobs and tubes, as previously described; the other that of providing a continuous raceway, or **conduit**, for the conductors.

One of the first conduit systems and one that came into very extensive use, though it is not now allowed by the Underwriters, was that of the Interior Conduit and Insulating Company. It was made of paper wound in an ingenious manner, so as to form a tube, and coated with tar inside and out. These tubes were installed as a continuous raceway from outlet to outlet, and one or two wires, as happened to be most convenient, were pulled into each conduit.

These paper tubes were very brittle, and the system was improved by covering them with a thin shell of sheet brass. Then came the requirement that the conduit should never contain more than one wire. At one time, "brass-covered interior conduit work" was considered the best possible kind of construction.

An excellent tube that may be used in some places, though not approved as a conduit proper, is the flexible **Circular-Loom** tube. This is a woven tube treated with insulating material that makes it hold its shape. It has no metal covering, but is stronger than the brass-covered interior conduit and more convenient to use. It will be permitted under the present rules only in special cases, as it is not waterproof or nail-proof. It is very useful for fished work in connection with knob-and-tube wiring and also for protecting wires at outlets. This tube must not be used in places exposed to moisture.

APPROVED CONDUIT SYSTEMS

40. The conduits now approved by the Underwriters are iron pipes with or without insulating lining, and flexible armored conduit made of interlocked steel tape. They are divided into two classes—*lined* and *unlined*. When unlined conduits are used, an additional braided covering must be placed on the wire, the idea being that the extra braiding on the wire takes the place of the lining in the pipe.

Formerly, most conduits were lined, but it is now customary to use unlined conduit with wire having extra heavy braiding. Twin wire is generally used, the two wires being covered with a common outer braiding.

Fig. 28 shows a piece of iron-armored, lined conduit; *a* is the armor about $\frac{1}{8}$ inch thick, which is the same as ordinary gas pipe; *b* is the insulating lining, not less than $\frac{1}{32}$ inch thick and adhering to the outer pipe. Conduit, whether lined or unlined, is put up in the same manner as a good job of gas-fitting. In fact, unlined conduit is practically the same as gas pipe except that the interior surface is galvanized, enameled, or otherwise treated to make it smooth and to keep it from rusting. Great care should be taken at the joints to see that the pipe is reamed and that the ends come together, so as to form a smooth runway (free from burrs) for the wire. In many places the conduit may be bent and the use of an elbow, with its threaded joints, avoided. There are several devices on the market for bending conduit, but about as good a way as any to bend conduit is to get a good stout piece of spruce or hard pine and bore a hole in it a little larger than the conduit. The pipe is then passed through the hole and the bend easily worked in. Another improvised form of bender is made by securing a short piece of $1\frac{1}{2}$-inch pipe into a $1\frac{1}{2}$-inch **T** and clamping the piece of pipe in a vise. The conduit can then be passed through the **T** and bent to any desired shape. For iron-conduit wiring, the wireman should be provided with a regular outfit of pipe-fitter's tools.

FIG. 28

41. Most conduit wiring is now carried out on the single-tube system, i. e., both wires or a twin wire are run in the same conduit. This plan requires less conduit and labor than the double-tube system and is, in fact, the only allowable arrangement when alternating currents are used. In the case of a large church, supposedly wired for 52 volts, 2 per cent. loss, the contractor ran the wires in separate pipes, with the result that when the current was turned on only 13 volts were obtained at the lamps. It is cheaper, as well as better, to use twin or concentric conductors in a single conduit, except for very large cables that are to carry direct currents.

42. Use of Outlet and Junction Boxes.—Since in any conduit system the primary object is to have the wires arranged so that they can be withdrawn, it is necessary, whenever a branch is taken off, to provide a **junction box** of some kind, because splices cannot be made at intervening points without interfering with the withdrawal of the wires. Conduit wiring is, therefore, done on the so-called **loop**

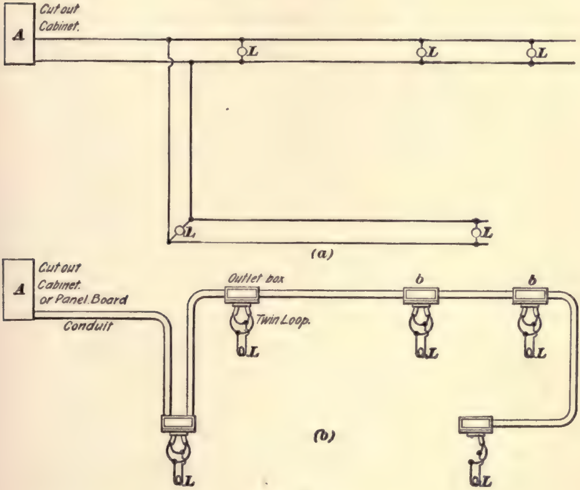


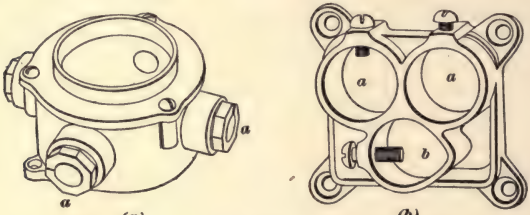
FIG. 29

system. This will be understood by referring to Fig. 29 (*a*) and (*b*); *L*, *L*, *L*, etc. are lamps on one circuit that is to be supplied from a panel board or distributing center located at *A*. In (*a*), the wiring is indicated as it might be done with the ordinary knob-and-tube system, using branches whenever they will reduce the labor and the amount of wire necessary; (*b*) shows the same lamps wired on the loop system, using outlet boxes *b* and looping out the twin wire at each lamp. No branches are taken off between outlet

boxes, and by disconnecting the wires running to the lamps, the main wires can be withdrawn.

The loop system using iron conduits is, of course, very much more expensive than the knob-and-tube system. It is, however, much more permanent in character and is the only style now used in the best class of buildings. The best method of running the conduit, so as to save bends and make the conduit as short as possible, must be left to the judgment of the wireman. In laying out such wiring, he must remember that the two wires are run together and that he cannot make short cuts with single wires, as in knob-and-tube work.

43. Conduits less than $\frac{5}{8}$ inch inside diameter are not allowable, and an outlet box must be provided at each outlet. When branch lines are taken off, a junction box must be provided. Junction boxes and outlet boxes are manufactured in a large variety of forms to accommodate conduits coming into them from different directions. Fig. 30 (*a*) shows a round cast-iron junction box. These boxes should be



(*a*) (*b*)

FIG. 30

mounted firmly in the wall and be placed so that the surface will come flush with the plastering. The split nuts *a*, *a* hold the conduit in place.

Fig. 30 (*b*) shows an **outlet plate.** The conduit is clamped in openings *a* and the gas pipe is clamped in *b*. Outlet plates must not be used unless it is impossible to install a regular outlet box. Outlet boxes used with lined conduit must also be lined and all boxes, whether lined or

unlined, must be enameled, galvanized, or otherwise treated inside and outside so as to prevent rust. Very convenient junction and outlet boxes are now made of stamped steel and are arranged so that one or more openings may be made in the side by taking out a small disk. Fig. 31 shows a box of this kind. The conduit enters the box and, projecting through it about $\frac{1}{2}$ inch, is held in place by an insulating cap *a* that screws over the end on the inner side. A check-nut *b* screws up against the outside of the box. Fig. 32 shows these fittings more in detail. Boxes of this type may be suited to different locations by simply knocking out or removing the disks whenever openings are needed. This avoids the necessity of carrying a large number of different boxes in stock. Outlet boxes may be obtained that are provided with special covers to accommodate almost any make of flush switch.

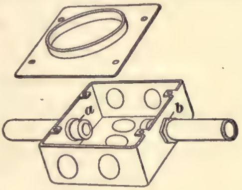


FIG. 31

When a change in the size of wire is made in a junction box, it is necessary to protect the smaller wire by a cut-out. Special cut-outs are made for mounting in junction boxes,

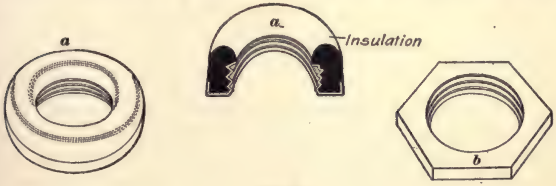


FIG. 32

but in most cases the wiring is laid out so that all fuses will be grouped on panel boards arranged in cut-out cabinets, each branch circuit running directly from the panel board to the lamps.

44. Fig. 33 shows one method of arranging a ceiling outlet for a combination fixture in a fireproof building

wired with iron-armored conduit. The floors are made of hollow tile placed between **I** beams. On top of the **I** beams wooden stringers are laid and the rough flooring is laid diagonally on these stringers. The finished floor is laid on top of the rough flooring. The gas pipes and electric conduit are laid in the space between the under side of the rough flooring and the top of the hollow tile. After the pipes and conduit have been laid, this space is filled with concrete. The conduit elbows and the gas pipe are brought down through the tile to the steel outlet box *a*. The ends of the conduit are provided with insulating nipples *b*, *b*, and the gas pipe *c*, where it passes through the box, is provided

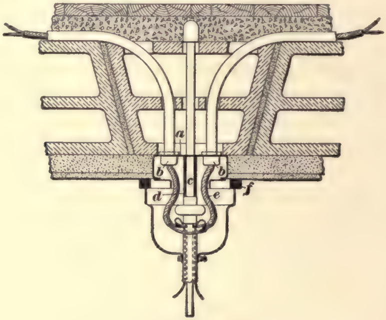


Fig. 33

with an insulating sleeve *d*. The wiring is on the loop system, the twin loop *e* being brought down from the conduit and the wires in it attached to the fixture wires as shown. The canopy is separated from the ceiling by the canopy insulator *f*. Of course the arrangement of outlets will differ considerably as to details, depending on the style of the outlet box used and the method of bringing down the conduit to the box. In general, the conduit should be brought down so as to necessitate as little cutting of the arch as possible; the outlet box should be well secured to the conduit, and the fixture must be firmly supported.

Fig. 34 shows an outlet for a fixture or bracket where the outlet box is mounted against a brick wall. In this case the outlet is for electric light only, and the fixture is supported by screwing it on to a threaded stud fastened to the back of the box. The outlet is wired on the loop system; hence, two conduits are necessary, one to bring the twin wire down and the other for the return. A double-pole wall switch would be wired in the same way, so far as the arrangement of outlet box and conduit is concerned, but the loops would, of course, be cut and the terminals attached to the switch. In some cases where outlet boxes are mounted on brick walls it may be necessary to cut out the brick so as to bring the outer edge of the box flush with the plaster, but generally the wooden strips, or furring, nailed on brick walls to take the lath will make sufficient depth between the surface of the plaster and the brick wall to take the outlet box. Outlet boxes should be secured in place by first drilling and plugging the brick and then fastening the box with screws or nails.

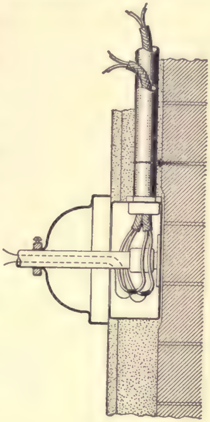


FIG. 34

When laying out a job of conduit wiring, the first thing to do is to locate the distribution cabinets and then the various outlets for lamps, switches, etc., as specified on the architect's plans. Too much care cannot be taken in properly locating these boxes; when a building is in rough condition with nothing in place other than rough walls or partitions, it is an easy matter to make mistakes in locating outlets, with the result that when the rooms are finished the outlets are found to be out of place and can only be fixed by doing some of the work over again or possibly by having to install molding. All outlet boxes should be put in place before any conduit is run; the wireman can then see just where the outlets are located and can plan the work so as to use the minimum

amount of conduit and labor. Switch outlets should be placed about 4 feet 3 inches from the floor and side-bracket outlets about 6 feet. Firm supports should be provided for outlet boxes in all cases; on ordinary walls or ceilings boards should be nailed across between the joists or studding.

45. Wire Used in Conduits.—Single wire used in lined conduit is the same as rubber-covered wire used for other low-voltage work. If twin wire is used, each conductor must comply with the requirements for other low-voltage, rubber-covered wire, except that each wire may be taped instead of braided, and there must be a braided covering over the whole. For unlined conduits, the same requirements hold, and in addition the wire must be provided with an extra braiding at least $\frac{1}{32}$ inch thick.

46. The following are some of the more important rules relating to the installation of conduits:

Interior Conduits—

The object of a tube or conduit is to facilitate the insertion or extraction of the conductors, and to protect them from mechanical injury. Tubes or conduits are to be considered merely as raceways, and are not to be relied on for insulation between wire and wire or between the wire and the ground.

a. No conduit tube having an internal diameter of less than $\frac{5}{8}$ inch shall be used; measurement to be taken inside of metal conduits.

b. Must be continuous from one junction box to another or to fixtures, and the conduit tube must properly enter all fittings.

In case of underground service connections and main runs, this involves running each conduit continuously into a main cut-out cabinet or gutter surrounding the panel board, as the case may be.

c. Must be first installed as a complete conduit system, without the conductors.

d. Must be equipped at every outlet with an approved outlet box or plate.

Outlet plates must not be used where it is practicable to install outlet boxes.

In buildings already constructed where the conditions are such that neither outlet box nor plate can be installed, these

appliances may be omitted by permission of the Inspection Department having jurisdiction, provided that the conduit ends are bushed and secured.

e. Metal conduits, where they enter junction boxes and at all other outlets, etc., must be provided with approved bushings fitted so as to protect wire from abrasion, except when such protection is obtained by the use of approved nipples, properly fitted in boxes or devices.

f. Must have the metal of the conduit permanently and effectually grounded.

It is essential that the metal of conduit systems be joined so as to afford electrical conductivity sufficient to allow the largest fuse or circuit-breaker in the circuit to operate before a dangerous rise in temperature in the conduit system can occur. Conduits and gas pipes must be securely fastened in metal outlet boxes so as to secure good electrical connection. Where boxes used for centers of distribution do not afford good electrical connection, the conduits must be joined around them by suitable bond wires. Where sections of metal conduit are installed without being fastened to the metal structure of buildings or grounded metal piping, they must be bonded together and joined to a permanent and efficient ground connection.

g. Junction boxes must always be installed in such a manner as to be accessible.

h. All elbows or bends must be so made that the conduit or lining of same will not be injured. The radius of the curve of the inner edge of any elbow not to be less than $3\frac{1}{2}$ inches. Must have not more than the equivalent of four quarter bends from outlet to outlet, the bends at the outlets not being counted.

47. While a conduit system is considered merely as a system of raceways for the wires, if it is properly installed, all joints firmly made, and an efficient ground provided, it serves the purpose also of an additional protection. No ground can then occur anywhere in the concealed wiring in the building except on the conduit, and if that is grounded to the earth, it cannot do any damage. If two grounds should occur on opposite sides of the line, a "dead" short circuit would be formed through the walls of the iron pipe. This will blow the fuses on the lines affected, disconnecting them, but doing no other damage. In a job of conduit wiring,

the conduit is, of course, installed during the construction of the building before lathing and plastering are done. The wires are, however, not drawn in until all rough work on the building is completed [note rule (*c*)].

There has been much discussion as to what constitutes a permanent and effectual ground in such work. In small installations the ground should be of as great carrying capacity as the conductors within the conduit. In large plants this is not practicable. Where conduits pass from junction box to junction box, they should be well connected, electrically as well as mechanically, to the metal of the boxes, so that no part of the conduit system will be insulated from or in poor contact with the rest of the system. If good contact cannot be made between the pipe and box, the pipe should be carefully cleaned on each side and a copper-wire jumper connected around the box.

Screw joints between various lengths of pipe and between pipes and junction boxes and cut-out cabinet frames are to be preferred to all other kinds of joints, because they are more secure and afford better electrical contact. To secure them in an entire system, it is necessary to use a few right-hand and left-hand couplings or a few unions. Where unions are used, they should preferably be of brass, because brass gives better contact at the sliding joints than iron. In most cases, however, instead of a union or right-hand and left-hand coupling, the thread is cut well back on one piece, the coupling screwed on and afterwards screwed back over the other piece.

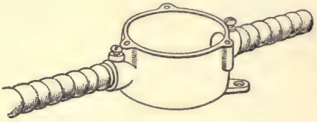


FIG. 35

But owing to the difficulty of installing screw joints in all places, and because other joints are easier to make and require less expensive fittings (though not so good), many systems have been designed in which other kinds of joints are relied on. Whatever system is used, the workman must not shirk the duty of making good pipe connections, which are as important as soldered joints on the wires.

48. Flexible Armored Conduit.—In order to avoid joints and make the conduit cheaper and easier to install, **flexible armored conduits** have been brought forward. Fig. 35 shows a piece of the Greenfield conduit and the

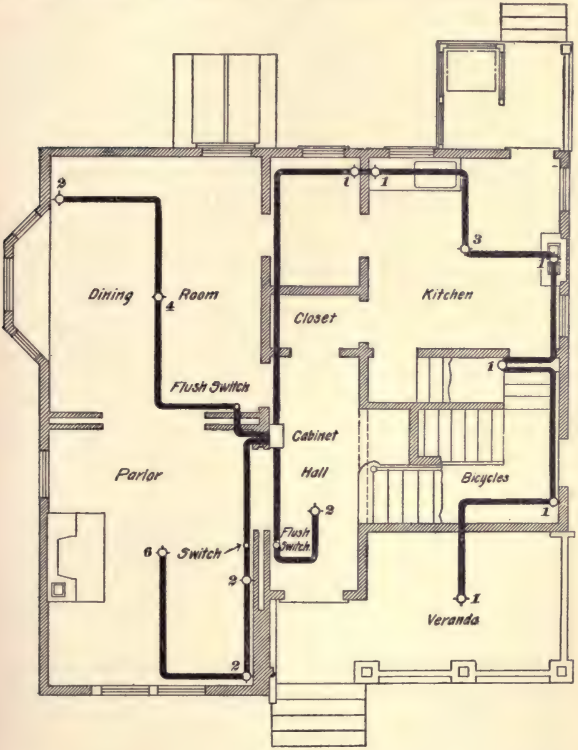


FIG. 36

method of connecting it to a junction box. This conduit is made of interlocked steel ribbon wound spirally. It affords a good protection to the wire against mechanical injury and

is easily installed, but it is not waterproof. It is, therefore, inferior to the iron conduit for damp places or where the conduit has to be laid in concrete.

49. Drawing Wires in Conduits.—When the wires are to be drawn into conduits, soapstone should be blown through first, as it makes the wire slide through more easily and take the ells better. A "snake" is first run through the tube and the wire pulled through by means of it. The *snake* usually consists of a steel ribbon about $\frac{1}{8}$ inch wide with a ball about $\frac{1}{4}$ inch diameter on the end. If the conduit has many turns, it is advisable to use a coiled spiral spring about $\frac{1}{4}$ inch diameter and 6 or 8 inches long with a ball on one end and the other end fastened securely to the steel ribbon. The end with the piece of spring is pushed in first and the spring passes around the turns easily.

Fig. 36 shows one floor of a dwelling house wired with conduit. The numbers on the various outlets indicate the number of lamps supplied. The wiring is carried out on the loop system, and it will be noticed that no branches are taken off between outlets. Four circuits are used in order that there may not be more than ten lamps on any one circuit.

WOODEN MOLDINGS

50. Wooden moldings are used for running wires over woodwork, on walls, door and window frames, and other places where they cannot otherwise be well concealed. Moldings put up on ceilings or walls should be arranged symmetrically, so as to disguise their purpose, even though it may be necessary to put up blank molding for this purpose. Work of this kind is confined almost exclusively to old buildings, and molding should not be used where it can be avoided. The following rules relate to moldings:

Wooden Moldings—

a. Must have both outside and inside at least two coats of waterproof paint or be impregnated with a moisture repellent.

b. Must be made of two pieces, a backing and capping and must afford suitable protection from abrasion. Must be so constructed as to thoroughly incase the wire and provide a $\frac{1}{2}$-inch tongue between the conductors and a solid backing that, under the grooves, shall not be less than $\frac{3}{8}$ inch in thickness.

It is recommended that only hardwood molding be used.

Wires—

For molding work:

Must have approved rubber-insulating covering.

Must never be placed in molding in concealed or damp places or where the difference of potential between any two wires in the same molding is over 300 volts.

51. Irresponsible parties sometimes run weather-proof wire in moldings. This practice is dangerous, for there is practically no insulation except that on the wire, if the molding becomes damp; in cleat and tube work there is an air space, and in conduit work an iron pipe, as an additional protection. Moreover, a wire with an air space or an iron jacket around it cannot do much damage even if it does become very hot; but a wire embedded in wood if overloaded excessively will char and possibly set fire to the wood,

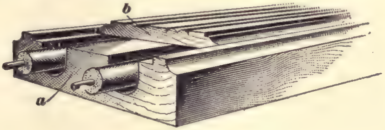


Fig. 37

because the heat cannot easily be dissipated. For these reasons molding work is now prohibited in some of the larger cities. Dampness is the greatest enemy of molding work.

However, where hardwood moldings and rubber-covered wires of sufficient size are used in places always dry, this kind of work is quite safe. Moldings are especially convenient in running border lights around the walls of rooms, and in wiring for temporary displays, and other work of a

semipermanent nature. They should not be run on brick walls where there is liability of moisture working through from the back. They are made in a variety of styles, some of which are ornamental and nicely finished to match the trimmings of the rooms in which they are used. Fig. 37 shows a typical two-wire molding that conforms to the Underwriters' requirements, since it has the backing *a* and capping *b*.

TESTS

52. After a job of wiring has been completed, **tests** should be made to see that all connections are correct and also that there are no grounds or crosses between the wires. All circuits should be tested before fixtures of any kind are put up, and each fixture should be tested carefully before it is

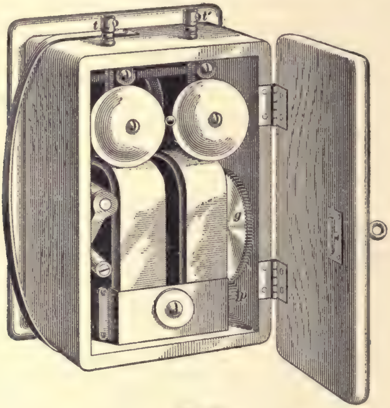


FIG. 38

put in place. Fixtures when received from the factory are not usually wired, and connecting the sockets, etc. must be done before they are put in place. If this is not carefully done, the fixture wire is apt to become grounded; hence, the necessity of testing out fixtures before they are put into

position. For most of this testing a **magneto-bell** is used. This is a small hand-power electric generator connected with a bell similar to the call bell on a telephone. In Fig. 38, t, t' are the terminals to which wires are attached in order to test any circuit; when a circuit is established between them the bell rings. These instruments are designed to ring the bell through resistances of 5,000 to 10,000 ohms, or more.

53. Each branch circuit should be tested by connecting its terminals at the panel board or cut-out with the magneto. The wires at all the outlets should be separated and the circuit rung up. If no ring is obtained, it shows that there is no cross between the wires. The wires coming out of each outlet should then be touched together in turn and also their corresponding switch outlets, if there are any, to see if the connections to the outlets are all right. After each outlet is rung up, its wires should be left separated. Each side of the circuit should then be tested for grounds. If it is a conduit system, one terminal of the magneto should be connected to the sheathing and the other to each side of the circuit in turn. If no ring is obtained on either side, it shows that the wire is clear of grounds. If a ring is obtained, the ends should be carefully examined, and if necessary the wire must be drawn out and examined. In knob-and-tube work the method of testing is practically the same, only in testing for grounds one side of the magneto may be connected to a gas or water pipe. Each fixture should be subjected to similar tests, and after all the fixtures are in place, the system as a whole should be tested.

54. Underwriters' Tests.—An insurance inspector usually tests each branch line with a magneto for continuity, short circuits, and grounds. He then usually counts up the number of lamps on each circuit and notes the sizes of wire used to see that no wire is overloaded when all the lamps are on. Concealed work must be inspected before the lath and plaster are put on, otherwise it will not be passed without special investigation; this means tearing up floors and walls, which is expensive to say the least.

In most installations, where the inspector has no reason to suspect that any faulty material has been used, he is able to satisfy himself by these tests and by examining the work with his eye; in fact, in many cases an ocular inspection is the only inspection made by the authorities, if they are satisfied that the contractor is honest and has made the other necessary tests.

55. Where more particular attention is given to a piece of work or where it is desired to learn whether an old installation or one not properly inspected at the time the work was done is up to the standard of safety, the insulation resistance is measured.

Insulation Resistance—

> The wiring in any building must test free from grounds; i. e., the complete installation must have an insulation between conductors and between all conductors and the ground (not including attachments, sockets, receptacles, etc.) of not less than the following:
>
> | | |
> |---|---|
> | Up to 5 amperes . . . . . | 4,000,000 ohms |
> | Up to 10 amperes . . . . . | 2,000,000 ohms |
> | Up to 25 amperes . . . . . | 800,000 ohms |
> | Up to 50 amperes . . . . . | 400,000 ohms |
> | Up to 100 amperes . . . . . | 200,000 ohms |
> | Up to 200 amperes . . . . . | 100,000 ohms |
> | Up to 400 amperes . . . . . | 50,000 ohms |
> | Up to 800 amperes . . . . . | 25,000 ohms |
> | Up to 1,600 amperes . . . . . | 12,500 ohms |
>
> All cut-outs and safety devices should be in place when the above test is made.
>
> Where lamp sockets, receptacles, and electroliers, etc. are connected, one-half of the above will be required.

Where lamps or other devices are suspected of taking more current than they should or where the load on any line is, for any reason, in doubt, the current should be measured with an ammeter.

MEASUREMENT OF DROP, IN VOLTS

56. If the current can be turned on in order to make a test of the drop in voltage, the best way is to use a voltmeter and determine the actual drop on each line at full load. With an ordinary voltmeter, the best method is to have two pairs of test cords and plugs connected to a double-pole double-throw switch. One pair of test cords should run to the distribution center; the other should run to the fixture to which the drop is to be determined. The switch should be so connected to the voltmeter that a reading of the voltage at the end of one pair of cords can be taken one instant and that at the end of the other pair of cords the next. The difference is the drop, in volts, on that line. All of the lamps should be turned on while the measurements are being taken, and several sets of readings should be made, because currents supplied from central stations suffer variations in voltage.

MARINE WORK

57. Wiring on board ships is subjected to some special conditions and therefore requires special treatment. The first important condition not usually met with on land is the motion of the ship, which makes it necessary to avoid all forms of construction where chafing or breaking might take place. The second important peculiarity is the constant dampness of the atmosphere. For these and other reasons a separate code has been prepared for marine work, from which the following rules are selected. They embody the chief points in which marine work differs from other work.

Wires—

a. Must be supported in approved molding or conduit except at switchboards and for portables.

Special permission may be given for deviation from this rule in dynamo rooms.

b. Must have no single wire larger than No. 12 B. & S. Wires to be stranded when greater carrying capacity is required. No single solid wire

smaller than No. 14 B. & S. except in fixture wiring to be used.

Stranded wires must be soldered before being fastened under clamps or binding screws, and when they have a conductivity greater than No. 10 B. & S. copper wire, they must be soldered into lugs.

c. Splices or taps in conductors must be avoided as far as possible. Where it is necessary to make them, they must be so spliced or joined as to be both mechanically and electrically secure without solder. They must then be soldered, to insure preservation, covered with an insulating compound equal to the insulation of the wire, and further protected by a waterproof tape. The joint must then be coated or painted with a waterproof compound.

Wires for Molding Work—

a. Must have an approved insulating covering.

The insulation for conductors, to be approved, must be at least $\frac{3}{32}$ inch in thickness and covered with a substantial waterproof and flame-proof braid.

The physical characteristics shall not be affected by any change in temperature up to 200° F. After 2 weeks' submersion in salt water at 70° F., it must show an insulation resistance of 100 megohms per mile after 3 minutes' electrification with 550 volts.

b. Must have, when passing through water-tight bulkheads and through all decks, a metallic stuffing tube lined with hard rubber. In case of deck tubes, they shall be boxed near deck to prevent mechanical injury.

c. Must be bushed with hard-rubber tubing $\frac{1}{8}$ inch in thickness when passing through beams and non-water-tight bulkheads.

Wires for Conduit Work—

a. Must have an approved insulating covering.

The insulation for conductors for use in lined conduits, to be approved, must be at least $\frac{3}{32}$ inch in thickness and be covered with a substantial waterproof and flame-proof braid. The physical characteristics shall not be affected by any change in temperature up to 200° F.

After 2 weeks' submersion in salt water at 70° F., it must show an insulation resistance of 100 megohms per mile after 3 minutes' electrification with 550 volts.

For unlined metal conduits, conductors must conform to the specifications given for lined conduits,

and in addition have a second outer fibrous covering at least $\frac{1}{32}$ inch in thickness and sufficiently tenacious to withstand the abrasion of being drawn through the metal conduit.

b. Must not be drawn in until the mechanical work on the conduit is completed and the same is in place.

c. When run through coal bunkers, boiler rooms, and where they are exposed to severe mechanical injury, must be incased in approved conduit.

TABLE V

TABLE OF CAPACITY OF WIRES FOR MARINE WORK

B. & S. G.	Area. Actual Circular Mils	Number of Strands	Size of Strands B. & S. G.	Amperes
19	1,288			
18	1,624			3
17	2,048			
16	2,583			6
15	3,257			
14	4,107			12
12	6,530			17
	9,016	7	19	21
	11,368	7	18	25
	14,336	7	17	30
	18,081	7	16	35
	22,799	7	15	40
	30,856	19	18	50
	38,912	19	17	60
	49,077	19	16	70
	60,088	37	18	85
	75,776	37	17	100
	99,064	61	18	120
	124,928	61	17	145
	157,563	61	16	170
	198,677	61	15	200
	250,527	61	14	235
	296,387	91	15	270
	373,737	91	14	320
	413,639	127	15	340

Portable Conductors—

Must be made of two stranded conductors, each having a carrying capacity equivalent to not less than No. 14 B. & S. wire, and each covered with an approved insulation and covering.

Where not exposed to moisture or severe mechanical injury, each stranded conductor must have a solid insulation

at least $\frac{1}{32}$ inch in thickness and must show an insulation resistance between conductors and between either conductor and the ground of at least 50 megohms per mile after 2 weeks' submersion in water at 70° F., and be protected by a slow-burning, tough-braided, outer covering.

Where exposed to moisture and mechanical injury—as for use on decks, holds, and firerooms—each stranded conductor shall have a solid insulation, to be approved, of at least $\frac{1}{32}$ inch in thickness and be protected by a tough braid. The two conductors shall then be stranded together, using a jute filling. The whole shall then be covered with a layer of flax, either woven or braided, at least $\frac{1}{32}$ inch in thickness, and treated with a non-inflammable, waterproof compound. After 1 week's submersion in water at 70° F., it must show an insulation between the two conductors or between either conductor and the ground of 50 megohms per mile.

Wooden moldings must be constructed according to the requirements for ordinary interior-wiring work and in addition must conform to the following rules:

a. Where molding is run over rivets, beams, etc., a backing strip must first be put up and the molding secured to this.

b. Capping must be secured by brass screws.

Cut-Outs—

a. Must be placed at every point where a change is made in the size of the wire (unless the cut-out in the larger wire will protect the smaller).

b. In places such as upper decks, holds, cargo spaces, and firerooms, a water-tight and fireproof cut-out may be used, connecting directly to mains when such cut-out supplies circuits requiring not more than 660 watts energy.

c. When placed anywhere except on switchboards and certain places, as cargo spaces, holds, firerooms, etc., where it is impossible to run from center of distribution, they shall be in a cabinet lined with fire-resisting material.

d. Except for motors, searchlights, and diving lamps, shall be so placed that no group of lamps requiring more than 660 watts shall ultimately be dependent on one cut-out.

Fixtures—

a. Shall be mounted on blocks made from well-seasoned lumber treated with two coats of white lead or shellac.

b. Where exposed to dampness, the lamp must be surrounded by a vapor-proof globe.

c. Where exposed to mechanical injury, the lamp must be surrounded by a globe protected by a stout wire guard.

d. Shall be wired with same grade of insulation as portable conductors that are not exposed to moisture or mechanical injury.

e. Ceiling fixtures over 2 feet in length must be provided with stay-chains.

WIRING ESTIMATES

58. It is difficult to lay down any reliable rules to be used in estimating the cost of a proposed wiring job. As when estimating in other lines of work, experience must largely be relied on. The prices of labor and material vary so widely in different sections of the country that any general rules might lead to very inaccurate results. Moreover, these prices are always fluctuating. One frequently sees statements to the effect that certain kinds of wiring can be done for so much per lamp or so much per outlet, but it is evident that while such figures might be fairly correct so far as the average of a large number of installations is concerned, they might be far from correct when applied to individual cases.

59. The only way in which to obtain a fairly close estimate of the cost of a given installation is to prepare plans and lay out the circuits, marking the size of the wire and the capacity of the various switches and cut-outs required. By laying out these plans, the amount of wire, conduit, and other material required may be arrived at quite closely. The number of switches, cut-outs, etc. can be counted up and their cost estimated. In measuring the length of the circuits, do not forget to take into account the wire and material necessary for running up and down walls to switches or outlets. Margin should be allowed for such material as tape, solder, etc. The labor item will depend largely on whether the building to be wired is an old one or one in the process of construction, also on the style of wiring used, so

that the labor item can only be determined from a careful inspection of the premises to be wired and experience on work of a similar class. An ordinary two-story dwelling house wired on the concealed knob-and-tube system will require about 6 days' labor of a man and helper. Some small houses will require less than this. Old houses require a much larger expenditure of labor, because there is liable to be considerable molding work to be done.

It is unsafe to assume a certain cost per outlet in figuring on a job of wiring unless one has been doing considerable work of a certain class. As a rough guide, however, it may be stated that ordinary dwellings wired on the concealed knob-and-tube plan will cost from $2 to $3 per outlet. This, of course, does dot include the fixtures, but should cover the cost of snap switches and porcelain cut-outs. Ordinary exposed wiring can usually be run for $1 to $1.75 per drop, including rosettes, cord, and sockets, though, of course, very much depends on how closely the lights are grouped. It is evident that if the lamps are scattered very much, the cost of wire, porcelain fittings, and labor will be comparatively high, and this will increase the cost per drop. Wiring with iron-armored conduit is expensive, but it is substantial. For small installations, it will probably cost from $5 to $6 per outlet; in large installations, the cost will be somewhat less. It must be remembered that these figures are only approximate. The cost in different localities might vary widely from the above, and the only way to make a fairly close estimate is to lay out the circuits, make a list of the material needed, and estimate their cost and the probable labor required.

INTERIOR WIRING

(PART 3)

COMBINING SEVERAL WIRING SYSTEMS

STORE LIGHTING

1. A large electric-light installation generally requires many kinds of wiring, and there are usually special conditions that determine what kind of work is to be done in each locality. As an example, we will take the wiring system of a certain department store as it was actually put in.

After a careful study of the conditions existing, the managers of the store concluded that enclosed-arc lamps were best suited for the general illumination of their stores, and that incandescent lamps should be installed at desks, in closets and warerooms, and occasionally in show windows. Accordingly, the premises were wired for 250 enclosed-arc lamps and 500 incandescent lamps at 110 volts.

Separate feeder wires were run to the ten departments. Two dynamos were installed in the engine room in the subbasement, one of which was capable of supplying current for one-third of the lamps and would be used when the load was light, while the other was capable of operating two-thirds of the lamps and some small motors. When the entire load was on, the two generators operated in parallel.

2. In order that light could be secured in case of a breakdown of the plant, service wires from the Edison three-wire system were brought into the basement and connected to the switchboard in such a manner that this current could

be used. The double-throw switches and connections necessary to change over from the two-wire to the three-wire system, where arc lamps are used, are shown in diagram in Fig. 1 (*a*). A special four-pole double-throw switch was installed. If there had been no arc lamps requiring the direction of the current to be constant, one three-pole double-throw

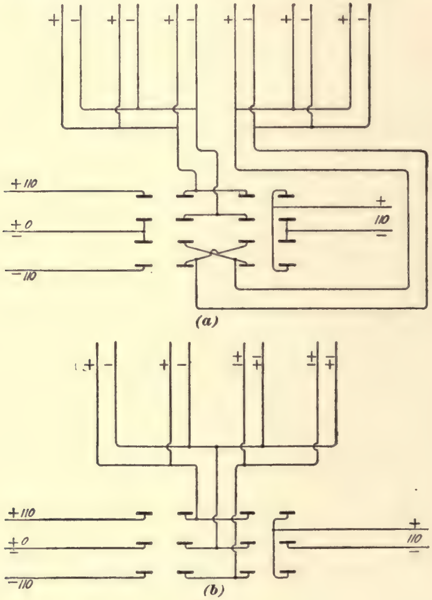


FIG. 1

switch, connected as in Fig. 1 (*b*), would have been sufficient. The use of the three-wire system in this case involved no saving in the lines, as that system extended only to the main switchboard, beyond which the two-wire system was used.

3. The large feeder cables were run from the engine room to the centers of distribution in each of the various

departments, in iron-armored conduits, one cable to a conduit. Cables and not wires were used, because heavy solid conductors cannot be drawn into conduits with bends in them. These conduits were put together with screw couplings and corner boxes of special design at each elbow, as the cables were very heavy. In the basement, the conduits were connected together by locknuts and a bus-bar, which was grounded to the water main back of the main valve on the automatic-sprinkler system by an iron rod, which was inserted in the water pipe like a tap. This afforded an excellent ground.

4. Cut-out cabinets were installed in each department. When in conspicuous places, they contained marble tablets on which were mounted lugs to receive fuses. Enclosed fuses were used and a switch was provided on the tablet for each circuit. The tablets were mounted in hardwood cabinets with plate-glass doors that opened by sliding downwards like a window sash. In less conspicuous places, the cabinets were provided with hinged wooden doors, were lined with asbestos, and provided with porcelain cut-outs of the enclosed-fuse type. For each enclosed-arc lamp, a separate branch line was run from the nearest cut-out cabinet. Large departments were provided with several cut-out cabinets connected to the same pair of feeders.

5. The branch lines were run in various ways; some of them were run in pipes, some in molding, and some were run open. Where placed in pipes, twin conductors were used and the lamps were hung from the pipe ends by means of an insulating joint. All branch pipes were connected together and to the feeder pipes at the cut-out cabinet in the same way as the feeder pipes were connected together in the basement.

6. A drop of 2 volts was allowed in the mains and a drop of 1 volt in the distributing wires for incandescent lamps. All distributing wires for the arc lamps were No. 14, and the resistances at the lamps were adjusted so as to secure 80 volts at the arc. From a distribution closet in one of the busiest departments, twin conductors of No. 14 wire were

run to the generator switchboard, in an iron pipe, and connected to a voltmeter on the switchboard. The terminals of these pressure wires in the closet were connected, with proper cut-out protection, to the terminals of the feeders. The dynamo tender was, therefore, able from the indications of the voltmeter to regulate his machines so as to maintain a constant potential of 110 volts at the cabinets.

7. The show windows were lighted by enclosed-arc lamps hung in the space above the goods displayed, but out of sight from the street. Only the outer globes projected below the dust-proof casing surrounding the window space. Thus, brilliant illumination was secured with very little glare and with great economy. The lamps were so arranged that they could be lifted out of the globes whenever it was necessary to trim them; but the globes were never removed, being cleaned while in place. This arrangement proved very effective and convenient. Additional circuits were run to various points for connecting incandescent lamps and special apparatus for holiday displays.

THEATER WIRING

8. The wiring of theaters and entertainment halls presents some peculiar features. All the lamps must be controlled from one point, usually on the right wing of the stage. Most of the lights on the stage are arranged in borders, or long rows, that contain several circuits of lamps of various colors, and are also usually provided with dimmers. Therefore, the stage switchboard of a large theater is quite a complicated affair compared with the distribution closets used in ordinary work.

In cases where there are a large number of borders of incandescent lamps, it is inconvenient to divide them into circuits of only 660 watts, and permission can usually be obtained from the Underwriters to place more lamps on such circuits if special care is taken.

9. **Stage dimmers** are of two kinds—*resistance boxes* and *reactive coils.* The latter are more economical, but can be

used with alternating currents only. Resistance boxes can be used with either direct or alternating current. Care must be taken to locate them where they can be kept cool by the circulation of fresh air. Reactive coils cut down the E. M. F. applied to the lamps by inserting a counter E. M. F. in the circuit. All kinds of stage dimmers must be thoroughly fireproof in construction and must be mounted on fireproof frames so that there will be no possibility of their setting fire to adjacent objects. Old-style resistance boxes were frequently provided with wooden casings, but this is no longer permitted. There are many reliable types of fireproof dimmers and they can be obtained for almost any desired range of current and voltage. In selecting dimmers of the resistance type, care should be taken to see that all sliding contacts are of ample capacity and substantially constructed.

Most of the dimmers in common use consist of a resistance split into a number of sections, so that the amount of resistance in series with the lamps may be varied. They are made in a number of different forms, some of them being arranged so that their operating handles interlock, allowing them to be operated singly or together in any desired combination. Dimmers are, of course, connected *in series* with the circuits that they are intended to control.

WIRING FOR SPECIAL PURPOSES

10. While in most work of a permanent character the closet or cabinet system of distribution, with very slight drop in the branch lines, is the proper system to adopt, there are special conditions that sometimes make it desirable to install wires for a very low price, for temporary or occasional use. In such installations, the efficiency is of comparatively little importance, but the proper regulation and uniform voltage at the lamps are as important as in permanent work.

11. Let us take a case, such as the installation of a thousand 8-candlepower lamps for decorative purposes around the cornices of a building at a fair, where the wires will be up for a few days or weeks only. All the lamps are to be

burned at the same time. In such a case, it may be economical to allow as much as 12.5 per cent. drop on the lines and use 100-volt lamps on 112.5-volt service. One pair of feeder lines will be run around the building, a distance of 1,000 feet. It is desired to have the drop such that there will be 100 volts at any point between the lines when 112.5 volts is applied at the terminals; this can only be accomplished by running the lines in opposite directions and having them change in size often enough to secure practically uniform drop per foot. Fig. 2 (*a*) illustrates such an arrange-

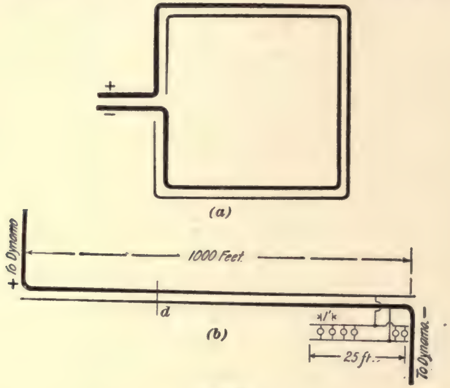


Fig. 2

ment, and (*b*) shows the same thing drawn in a straight line instead of a square. This is sometimes called the *anti-parallel* method of feeding.

12. There will be a lamp for every foot, and there will be required forty branches of No. 14 wire, with 25 lamps on each branch, as shown in Fig. 2 (*b*). Weatherproof wall receptacles will be used. The total length of wire in the mains is 2,000 feet. The length of wire to any given branch is 1,000 feet; hence, the rate of drop must be 12.5 volts per 1,000 feet. On account of the method of feeding from each end, it is easily seen in Fig. 2 (*b*) that

the length of wire through which the current flows to any point *d* must be 1,000 feet. The currents that various wires will carry with a drop of 12.5 volts are as follows:

Size of Wire	Volts Drop		Resistance per 1,000 Feet		Amperes
No. 14	12.5	÷	2.521	=	4.96
No. 12	12.5	÷	1.586	=	7.88
No. 10	12.5	÷	.997	=	12.5
No. 8	12.5	÷	.627	=	19.9
No. 6	12.5	÷	.394	=	31.7
No. 5	12.5	÷	.313	=	39.9
No. 4	12.5	÷	.248	=	50.4

The amperes for larger wires can be found by consulting the tables in *Interior Wiring*, Part 2.

Since the lamps are to be 8 candlepower, there will be about 1 ampere for every four lamps, and consequently for every 4 feet of line (two wires). In making up a conductor to have nearly uniform drop, it will be necessary to compromise for all points that do not exactly correspond with the above-calculated current values. For instance, if No. 12 wire is joined to No. 14, it must be at a point where there is between 4.96 and 7.88 amperes. If lengths of wire are selected so that this joint will come half way between the points where the wires exactly correspond, it will be near enough. The results will then be as tabulated on the following page.

In this table the second column is obtained by dividing the volts drop (12.5) by the resistance per 1,000 feet of the various sizes of wire. The third column is found by taking the approximate value of the current multiplied by 4 because there is 1 ampere for every 4 feet of cornice. The fourth column is obtained by taking one-half the difference between the succeeding quantities in the third column and adding this difference to the quantity in the third column. For example, at a point 20 feet from the end, the current is 4.96 amperes and at a point 32 feet from the end it is 7.88 amperes. As stated above, lengths of wire will be selected so as to

bring the joints between the different sizes of wire midway between the points where the wires correspond. Hence, in the first case, if there is a current of 7.88 amperes 32 feet from the end and a current of 4.96 amperes 20 feet from the end, the joint will be $20 + \frac{32 - 20}{2} = 26$ feet from the end and 26 feet of No. 14 wire will be required. Also, in the case of the No. 8 and No. 6 wires, there is a current of 19.9 amperes 80 feet from the end and 31.7 amperes 127 feet

Size of Wire	Amperes Giving 12.5 Volts per 1,000 Feet	Corresponding Distance From End of Line	Distance of End of Wire From End of Line	Length of Wire to Be Used
14	4.96	20	26	26
12	7.88	32	41	15
10	12.5	50	65	24
8	19.9	80	104	39
6	31.7	127	144	40
5	39.9	160	181	37
4	50.4	202	228	47
3	63.5	254	287	59
2	80.1	320	362	75
1	100.8	403	457	95
0	127.5	510	576	119
00	160.3	641	724	148
000	201.6	806	913	189
0000	255.1	1,020	1,000	87

from the end; hence, the joint between the two sizes will be $80 + \frac{127 - 80}{2} = 103.5$ feet from the end. In the table, the nearest even number of feet is given, so that this is taken as 104. In the case of the 0000 wire, the distance from the end of the line corresponding to a drop of 12.5 volts works out 1,020 feet, though, of course, there will not be quite as large a current as 255.1 amperes because the line cannot be

longer than 1,000 feet. This quantity is, however, used in determining the distance (913 feet) of the end of the 000 wire from the end of the line. The distance of the end of the 0000 wire must, of course, be 1,000 feet because the cornice is 1,000 feet long. The lengths in the fifth column are obtained by subtracting the successive values of the fourth column, for example, 65 − 41 = 24, 104 − 65 = 39, etc.

13. Cut-outs will have to be installed as follows:

15 amperes, to protect Nos. 14, 12, and 10
25 amperes, to protect No. 8
65 amperes, to protect Nos. 6, 5, 4, and 3
130 amperes, to protect Nos. 2, 1, and 0
160 amperes, to protect No. 00
250 amperes, to protect Nos. 000 and 0000

This statement assumes that weather-proof wire is to be used. Fig. 3 is a diagram of a portion of the wiring in place, showing the connections of cut-outs.

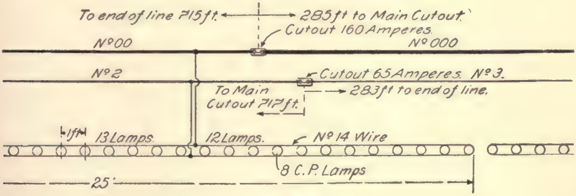


FIG. 3

14. Another method of wiring for temporary work is to put up wires on the feeder system just large enough to carry the current, and then calculate the drop and install lamps of the required voltage. This is a simple and very cheap method. In the case of the border lamps just considered, there would be eight pairs of feeders of No. 10 wire, with 125 lamps per feeder. If they are arranged as shown in Fig. 4, the lengths of these feeders and the drop on each may be, roughly, as follows, if each lamp required $\frac{1}{4}$ ampere. Current in each feeder is $\frac{125}{4}$ amperes, and No. 10 wire has a

resistance of about 1 ohm per 1,000 feet. The approximate lengths of the feeders will be as given below:

Two lines 425 feet (two wires) long, 26.6 volts drop
Two lines 300 feet (two wires) long, 18.8 volts drop
Two lines 175 feet (two wires) long, 10.9 volts drop
Two lines 50 feet (two wires) long, 3.1 volts drop

The resistance of 425 feet (.425 thousand feet) of No. 10 wire is, approximately, .425 ohm and the drop in the first case $= \frac{125}{4} \times .425 \times 2 = 26.6$. The others are found in a similar manner. In the distribution, about 1 volt would be lost. Consequently, if 125 volts is supplied, the lamps should have voltages of 97, 105, 113, and 121 if each lamp requires $\frac{1}{4}$ ampere.

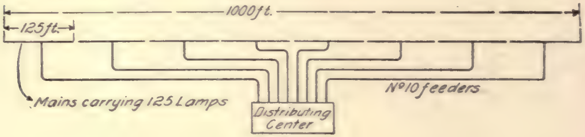


FIG. 4

15. There are many other methods or plans by which such a building could be wired for a large drop and still be furnished with uniform and steady light. These suggestions merely show how material may be saved. By making every installation a matter of special study, until he has thoroughly mastered every detail of the business, the wireman will discover many ways of economizing labor and material that cannot be brought to his attention in any other manner. Before using any unusual method, however, he should make certain that there is no objection on the part of the Underwriters or of the Fire Department to what he proposes to do.

HIGH-POTENTIAL SYSTEMS

16. The Underwriters' rules so far given apply to systems using 550 volts or less; for pressures over 550 volts, the following rules apply:

HIGH-POTENTIAL SYSTEMS

550 to 3,500 Volts

Any circuit attached to any machine or combination of machines which develops a difference of potential between any two wires of over 550 volts and less than 3,500 volts shall be considered as a high-potential circuit and as coming under that class, unless an approved transforming device is used which cuts the difference of potential down to 550 volts or less.

Wires—

a. Must have an approved rubber insulating covering.

b. Must be always in plain sight and never incased except where required by the Inspection Department having jurisdiction.

c. Must be rigidly supported on glass or porcelain insulators, which raise the wire at least 1 inch from the surface wired over, and must be kept about 8 inches apart.

d. Must be protected on side walls from mechanical injury by a substantial boxing, retaining an air space of 1 inch around the conductors, closed at the top (the wires passing through bushed holes) and extending not less than 7 feet from the floor. When crossing floor timbers in cellars or in rooms where they might be exposed to injury, wires must be attached by their insulating supports to the under side of a wooden strip not less than ½ inch in thickness.

17. It is never advisable to bring high-potential wires into a building when it can be avoided. The danger to life, due to their presence, is greater than the fire hazard. An arc on a high-potential circuit carrying much current, once

started, will continue to burn even when the points between which it plays are separated several inches; and a lightning discharge can easily start such an arc. High-potential systems of over 550 volts are usually alternating. Series arc-lighting circuits are the only important direct-current high-potential circuits much used in the United States. With the exception of arc lamps, it is seldom necessary to bring any high-potential wires inside of buildings. Where alternating current is used, the line pressure is lowered by means of transformers; and it is never necessary to bring the high-pressure wires farther than the substations or transformer rooms.

18. Transformers.—The ordinary alternating-current transformer consists of two coils of wire wound on an iron core built up of thin sheets of iron. One of these coils, the *primary*, has a comparatively large number of turns and is connected to the high-pressure line. The other coil, the *secondary*, has a small number of turns and is connected to the lamps or other devices to be supplied with current. The high-pressure current flows through the primary and sets up an alternating magnetism through the secondary and induces an E. M. F. that is proportional to the ratio of the number of turns in the secondary coil to the number of turns in the primary. For example, if the primary had five hundred turns and the secondary fifty, the secondary voltage would be $\frac{50}{500}$, or $\frac{1}{10}$ the primary voltage, and if the primary were supplied at 1,000 volts, the secondary would deliver 100 volts. Special attention should be given to the following rules governing the installation of transformers. Cut-outs on primary circuits must be of some pattern especially designed and approved for the purpose; ordinary fuse blocks must not be used for high voltages.

19. Rules Relating to Transformer Installation.

Transformers—

a. Must not be placed inside of any building, excepting central stations, unless by special permission of the Inspection Department having jurisdiction.

b. Must not be attached to the outside walls of buildings, unless separated therefrom by substantial supports.

(*When permitted inside buildings*)

a. Must be located at a point as near as possible to that at which the primary wires enter the building.

b. Must be placed in an enclosure constructed of or lined with fire-resisting material; the enclosure to be used only for this purpose, and to be kept securely locked and access to the same allowed only to responsible persons.

c. Must be effectually insulated from the ground and the enclosure in which they are placed must be practically air-tight, except that it shall be thoroughly ventilated to the outdoor air, if possible, through a chimney or flue. There should be at least 6 inches of air space on all sides of the transformer.

20. The greatest danger to be feared in the use of transformers is the grounding of the primary on the secondary wires. This may occur either on account of a breakdown of the insulation under working conditions or because of lightning striking the primary wires. Efficient protection against lightning is an essential part of the out-of-door and central-station equipment.

WIRING FOR ARC LAMPS

21. Constant-Potential Arc Lamps.—The use of arc lamps in parallel on low-potential circuits has already been considered. Wiring for these lamps is done in practically the same way as for incandescent lamps, so that no special comment is necessary. The following special rules relate to arc lamps operated on low-pressure circuits:

Arc Lights on Low-Potential Circuits—

a. Must have a cut-out for each lamp or each series of lamps.

The branch conductors should have a carrying capacity about 50 per cent. in excess of the normal current required by the lamp to provide for heavy current, required when lamp is started or when carbons become stuck. without overfusing the wires.

b. Must only be furnished with such resistances or regulators as are enclosed in non-combustible material, such resistances being treated as sources of heat. Incandescent lamps must not be used for resistance devices.

c. Must be supplied with globes and protected by spark arresters and wire netting around globe, as in the case of series arc lights.

Outside arc lamps must be suspended at least 8 feet above sidewalks. Inside arc lamps must be placed out of reach or suitably protected.

22. Constant-Current Arc Lamps.—Arc lamps used for street lighting are nearly always run in series. With this arrangement the same current flows through all the lamps and must be maintained at a constant value by the generator, no matter how many lights may be in operation. The voltage generated by the dynamo therefore varies with the load and the current remains constant. This is just the reverse of the constant-potential system. It is easily seen that if the number of lamps is at all large, the pressure applied to the circuit has to be very high; hence, arc lamps connected to such a circuit must be treated as being on a high-pressure system and wired accordingly. Series arc lamps are also used for indoor illumination, though not as extensively as formerly.

23. In all constant-potential installations, protective devices are installed to open the circuit whenever the lines are overloaded or the apparatus does not operate properly. In constant-current working, the circuit must never be opened while the dynamo is running. The protective devices used on constant-potential working must, therefore, never be installed on constant-current circuits.

All series-arc apparatus is thrown out of circuit by shunting or short-circuiting the main circuit before opening the lines on which the apparatus is connected. The switch should be constructed so that the lamp will be disconnected from the line after it has been shunted and the switch should indicate clearly whether it is on or off. It should also be semi-automatic in its action; i. e., when the handle has been

thrown the blades should be so actuated by springs that they will move quickly and not stop between points and thus draw an arc. The constant-potential arc lamp has proved such a success that it has largely replaced the series lamp for interior lighting, thus doing away with the high-tension wiring, which at best was always a necessary evil.

24. The general method of installing series arc-lighting wires is similar to that used in other high-tension interior work. They must be very thoroughly protected against accidental contact with anything not intended to connect with them.

Rubber-covered wire mounted in plain sight on porcelain insulators must be used and an approved service switch must be placed where the wires enter the building so that the high-tension current can be completely cut off by firemen or policemen in case of fire in the building. The wires must be kept at least 8 inches apart. It must be remembered that there is always a strong tendency for grounds to develop on series arc-light circuits on account of the high pressure used. For this reason the Underwriters' rules are particularly exacting regarding the insulation of interior wiring for this class of work, and all fittings used must be carefully selected; for example, ordinary snap switches are not allowed. In case it is necessary to run the wires up side walls, they must be protected by a boxing that will leave a clear air space of 1 inch around the wires. This boxing must be closed at the top in order to keep out dirt and rubbish and the wires must be bushed with porcelain tubes where they pass through the top of the casing.

The current supplied to constant-current arc lamps seldom exceeds 9 or 10 amperes and often it is as low as 6.6 amperes. As far as mere carrying capacity is concerned, No. 14 wire will be large enough to satisfy the Underwriters' requirements; but the wire is frequently of the same size as that used by the lighting company for the outside lines, which must be as large as No. 6 or No. 8 B. & S. in order to secure sufficient mechanical strength and also in order to reduce the drop in the line.

25. The tendency is to connect more and more arc lamps on a series circuit. In the early days of electric lighting, arc machines were made to operate 1, 2, or 3 lamps. The number was increased to 30 or 50, and finally to 60, where the limit remained for a few years. But machines are now built to operate as many as 125 lamps on a single circuit, and are in quite general use, although the Underwriters prohibit the bringing of circuits of more than 3,500 volts (70 series arc lamps) within buildings. With 45 volts at the arc and 5 volts lost on the line for each lamp, we have on a 125-lamp machine a total potential difference of 6,250 volts. A shock received through the human body from such a circuit is almost sure to be fatal. Too much care cannot be taken not only to insulate the wires and locate them out of reach, but also to insulate the lamps. They should be hung from an approved form of hanger board or insulated supports, and not from hooks screwed into the ceiling.

26. Incandescent Lamps on Series Circuits.—The use of incandescent lamps connected in series for street lighting is quite extensive, but such lamps are rarely brought inside of buildings. When they are, the rules for other classes of high-potential work apply. Each lamp must be provided with an automatic cut-out and must be suspended from a hanger board by means of a rigid tube. Lamps must not be connected in series-parallel or parallel-series and under no circumstances should they be attached to gas fixtures.

Incandescent lamps used on series circuits must be provided with fittings designed for that purpose. The rule against series-parallel connections means that a connection such as twenty 110-volt lamps in parallel must not be placed in series with a 10-ampere arc-lighting system. The burning out of one or two incandescent lamps on such a system would throw too much current on the others, burn them out, and destroy the sockets. Many other reasons forbid such connections.

WIRING FOR ELECTRIC MOTORS

27. The wireman is frequently called on to connect up motors; these are nearly always operated at constant potential, and the wires are installed as for other wiring of this kind. They are usually operated on 110, 220, or 500 volts direct current or on similar voltages alternating current. Alternating-current motors are usually run on either the two- or three-phase system. Care should be taken to see that the interior wiring has sufficient capacity; to determine which, the current taken by the motor at full load should be known.

It is well to allow a liberal amount of current for small motors, because of their low efficiency. The efficiency of a large motor can be learned from the manufacturer; and high-grade high-priced machines are more efficient than cheap ones; this is a most important consideration to the purchaser. For the purposes of wiring, however, it is safe to figure 90 per cent. efficiency for motors over 10 horsepower in capacity, 85 per cent. for motors between 5 and 10 horsepower, 80 per cent. for motors between 2 and 5 horsepower, 75 per cent. for motors of 1 horsepower, and lower efficiencies for motors of smaller sizes. Alternating-current motors take somewhat more current for the same output than those operated on direct current. Table I gives the approximate value of the current in the lines for motors of various sizes and voltages. These figures will vary somewhat in individual cases, because the efficiency and other characteristics of motors vary considerably. The current taken by a motor at full load is usually given by the makers on the name plate of the machine. If it is not given, the table will serve as a guide in determining the size of wire to be used.

28. Motors should, whenever possible, be insulated from the ground by means of wooden base frames. This, however, can seldom be done when motors are mounted on machine tools or for similar work. The wiring must be carried out in the same way as required for lights. Where motors are mounted near or on machinery, special precautions

TABLE I

CURRENT REQUIRED BY MOTORS

Horsepower	Direct-Current Motors			Alternating-Current Motors								
				Single Phase			Two Phase (Four Wire)			Three Phase (Three Wire)		
	110 Volts	220 Volts	500 Volts	110 Volts	220 Volts	500 Volts	110 Volts	220 Volts	500 Volts	110 Volts	220 Volts	500 Volts
1	9	4.5	2.0	14	7	3.1	6.4	3.2	1.4	7.4	3.7	1.6
2	17	8.5	3.7	24	12	5.3	11	5.7	2.5	13	6.6	2.9
3	26	13	5.6	34	17	7.5	16	8.1	3.5	19	9.3	4.1
5	40	20	8.8	52	26	11	26	13	5.5	30	15	6.4
$7\frac{1}{2}$	60	30	13	74	37	16	38	19	8.1	44	22	9.3
10	76	38	17	94	47	21	44	22	10	50	25	12
15	112	56	25				66	33	15	76	38	17
20	150	75	33				88	44	19	102	51	22
30	226	113	50				134	67	29	154	77	33
40	302	151	66				178	89	39	204	107	45
50	368	184	81				204	102	45	236	118	52
75	552	276	122				308	154	68	356	178	77
100	736	368	162				408	204	90	472	236	104
150	1,110	555	244				616	308	135	710	355	156
200	1,474	737	324				818	409	180	940	470	208

must be taken to protect the wires by running them in pipe or flexible conduit. The branch circuits running from the mains to a motor should be designed to carry at least 25 per cent. more current than that for which the motor is rated, in order to allow for the large current at starting and for occasional overloads. A main switch must be provided that will open all wires leading from the mains to the motor unless the motor is less than $\frac{1}{4}$ horsepower and is operated on less than 300 volts, in which case a single-pole switch may be used. Each motor must also be provided with a cut-out, but if an automatic circuit-breaker that opens all the wires leading to the motor is used, the main switch and cut-out may be dispensed with and the automatic circuit-breaker made to serve both as switch and cut-out. A single-pole circuit-breaker cannot be used instead of the switch and cut-out; in any event it is advisable to equip motors with circuit-breakers, particularly if they are used to drive machinery likely to cause temporary overloads.

29. The switch and starting box should be located within sight of the motor and the starting box should be equipped with an automatic release attachment that will allow the rheostat arm to fly back to the off-position in case the power fails. Motors must not be run in series-parallel or parallel-series except on constant-potential systems, and then only by special permission.

The Underwriters' rules prohibit the operation of motors or lights from street-railway circuits, except in street cars, car barns, or railway power houses. The reason for this is that one side of a railway system is grounded to the rails, and the installation of motors or lights would always introduce more or less fire risk.

BELL WIRING

30. Electric bells, burglar alarms, and electric gas-lighting appliances bring in another class of wiring with which the wireman has to deal. If these appliances are put in properly, they may be a great convenience; if not, they are continually getting out of order and may prove to be a regular nuisance. This class of work is often slighted and put up in a cheap manner, but it will pay in the end to have it put up carefully. The bells and annunciators that show from what point the bell was rung are operated by primary batteries, which are of low voltage, and no fire hazard is introduced if the bell wires are kept well separated and insulated from electric light and power wires.

THE ELECTRIC BELL

31. The **electric bell** is a very simple piece of apparatus. Fig. 5 shows a skeleton bell, in which all the parts are visible. With the battery wires connected at the terminals t, t', the course of the current is: From the terminal t to the adjustment screw s, which is tipped with platinum in order to prevent oxidation of the contact surface, through the spring l and the end p of the armature to the coils of the magnets m, m', and out at the terminal t'. When no current is passing, the armature is held from the poles of the electromagnets, as in the position shown, but as soon as a battery circuit is closed and a current sent through the coils, the magnets become energized and attract the armature a, which swings about the pivot p, causing the hammer h to strike the bell. This movement breaks the circuit between s and l, and the iron cores being thereby demagnetized, the spring c draws the armature away, when the spring l again touches the screw s, completing the circuit. As long, then, as the battery current is free to flow, this vibration of

the armature and hammer will continue. The tension of the release spring c may be changed to suit the strength of the battery by means of the regulating screw r, which is provided with nuts on each side of the supporting pillar. The bell mechanism is usually enclosed to prevent entrance of dust or insects, which may interfere with the working of the bell by lodging on the contact points, thereby preventing the current from passing through the magnets.

32. The bell just described is of the common vibrating class. When a bell is required to give a single stroke each time the circuit is closed, that is, for each momentary flow of current, a slight difference in the connection of the ordinary bell is necessary. A wire is connected between the end of the magnet coil m and the terminal t, so that the circuit is simply from one terminal to the other through the coils. Hence, when a current passes through the coils, the armature is attracted and held, a single stroke being given to the bell; on interrupting the current, the armature is drawn back to its normal position by the spring c.

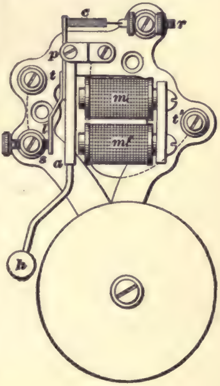


FIG. 5

33. The **buzzer,** shown in Fig. 6, is used in places where an electric bell would be undesirable, as in small, quiet rooms or on desks, and is constructed on the same principle as the bell except that the armature does not carry a hammer. In the illustration, the cover c is removed, showing the magnet coils m, m' and the armature a. An adjusting screw s is provided to regulate the stroke of the armature and the consequent intensity of sound. The wires from the push button and battery are secured at d and e, and on closing the circuit, the rapid vibration of the armature causes a humming or buzzing sound, whence the name.

Buzzers are generally used for signaling in places where a bell would make too much noise, as, for example, between the dining room and kitchen of a residence.

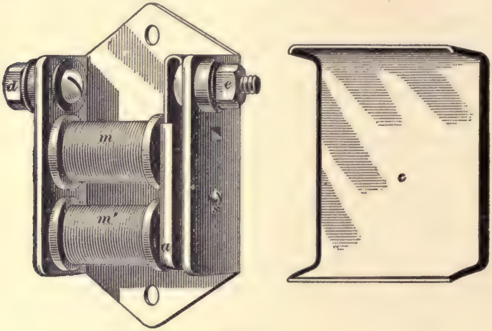


FIG. 6

34. The circuit-closing devices used on bellwork usually take the form of a **push button.** These are made in all sorts of styles. The very cheap wooden ones are seldom satisfactory and bronze push buttons should be used where exposed to the weather. Fig. 7 shows the ordinary round push button. The wires enter through holes in the base and attach to springs *b* and *c*; the cover *d* screws on. When *e* is pushed, *b* and *c* come together, and complete the circuit.

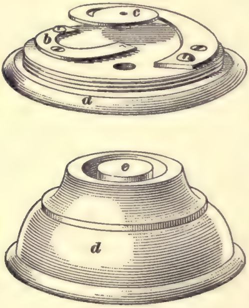


FIG. 7

One cell of any efficient type will ring a good bell over a short length of wire, but it is never advisable to rely on less than two cells, even in the smallest installations. When several cells are connected together to form a battery, the zinc of one must be joined to the carbon of the next and the free

terminals at the ends of the row of cells connected to the line wires.

35. Electric bells can be had of all sizes. Very cheap bells should not be used, as they require much battery power and soon get out of order. Trouble is usually found first at the contact points or the armature pivot. Contact points should be tipped with platinum or silver; platinum being much the better material for this purpose, as it never corrodes or tarnishes, but it is more expensive than silver, which is much used on cheap bells.

In an ordinary dwelling there are frequently three electric bells, one located at a convenient point in the rear hall with a push button at the front door; one in the kitchen with a push at the back door, and one, a buzzer, located in the kitchen with a push in the dining-room floor. These bells may all be operated by the same battery. The battery should be located in a cool place, but where it never is cold enough to freeze; preferably in the cellar, where the air is not so dry that the water in the cells evaporates rapidly. Cells should not be allowed to become dry. Water should be added from time to time so as to keep the level of the solution up to the proper height, which is usually marked on the glass jar.

BATTERIES

36. Many different types of cell are manufactured that are suitable for bellwork. Most of them are of the **open-circuit** type, which are intended to furnish current for short intervals only and will run down if used continuously. Crosses between the wires or grounds will often cause the cells to run down rapidly. Most of these cells will recover to a certain extent if allowed to stand for a while on open circuit, but they should never be allowed to become short-circuited if it is possible to avoid it.

The cells in ordinary use on bellwork have electrodes of zinc and carbon and contain a solution of sal ammoniac (ammonium chloride). Sometimes they also contain a

"depolarizing" agent, such as manganese dioxide. The effectiveness of a carbon-zinc cell depends largely on the materials of which the carbon element is made and the skill used in its manufacture. Burning the carbons too much or too little in the process of manufacture makes them inferior. Some manufacturers make inferior carbons and then treat them with sulphuric acid, to make them operate with vigor when first installed. Such cells soon become polarized, and in the course of a few weeks or months are very inferior, not because of the acid so much as because of the poor quality of the carbon. Dry cells are very convenient, but as a rule they do not last as long as wet cells. Sometimes they can be recharged by sending a current through them in a direction opposite to that in which they furnish current, but such recharging does not last long. When dry cells have run down, the cheapest and most satisfactory way in the end is to throw them away and get new ones. Suitable cells for bell operation are: Leclanché, Carbon Cylinder, Fuller Bichromate, Dry Cells, Gordon, and Edison-Lalande. The two last named are particularly useful on circuits where the insulation is poor and where there is, consequently, considerable leakage, as, for example, on signal circuits in mines.

37. In a few cases, as in certain burglar-alarm systems, the circuit is normally closed and the opening of the circuit interrupts the current. In these systems, the battery must be capable of furnishing current steadily; that is, it must be of the *closed-circuit type*. The *gravity cell* is a common closed-circuit type and is well adapted for work where a small steady current is desired; in fact, gravity cells will get out of order if allowed to stand for any great length of time on open circuit.

OPERATING BELLS FROM LIGHTING CIRCUITS

38. It is sometimes convenient to operate an electric bell from an incandescent lighting circuit. This may be done when direct current is used to operate the lamps, but if alternating current is used, an ordinary bell will work very

poorly, if at all. Of course, it is necessary to use a resistance in connection with the bell in order to limit the current; the amount of resistance will depend on the kind of bell used, because some require much more current than others. Incandescent lamps make a cheap and convenient form of resistance; Fig. 8 (*a*) shows a bell *a* and push button *b* in series with four lamps *l* across a 110-volt circuit. This is the simplest scheme of connection, but there is apt to be bad sparking at the contacts on the bell, because the voltage across the break rises to 110 volts at the instant the circuit

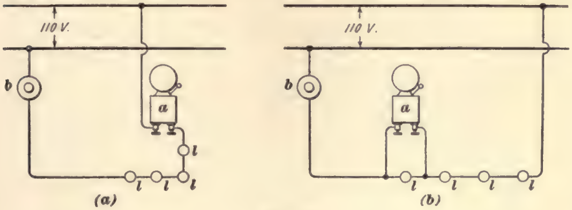


FIG. 8

is broken. View (*b*) shows the bell shunted across one of the lamps, in which case the voltage at the break is much smaller. The operation of bells from lighting circuits is not to be recommended and it will not be allowed by the Underwriters unless the whole of the bell wiring is installed in accordance with the wiring requirements for lighting circuits. Ordinary bell wiring put up with staples, etc. must *not* be connected to any source of pressure exceeding 10 volts, and it would be decidedly unsafe to connect it to a 110-volt circuit.

39. A better method of utilizing the lighting current for bell operation is through the medium of storage cells, as shown in Fig. 9. Two sets of cells *a*, *b* are connected to double-pole double-throw switches, as indicated. When both switches are thrown up, both sets of cells are charged from the lighting circuit. Normally, one set of cells will be charging while the other is in use, as indicated by the position of the switches in the figure. Of course, if the bell circuits are

such that they will not be used during certain hours each day, the cells can be charged during this interval and only one set will be needed. Storage cells are somewhat high in first cost as compared with ordinary primary cells, but one storage cell gives about twice the voltage of an ordinary sal-ammoniac cell, so that only half as many are required for

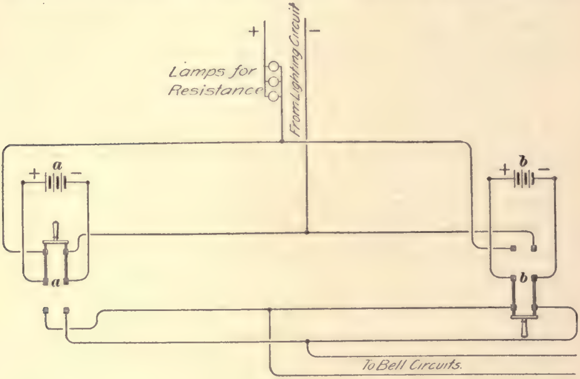


FIG. 9

a given voltage. In Fig. 9, lamps or some other form of resistance must be connected in series when charging the cells in order to limit the current. By using storage batteries, as shown in Fig. 9, the bell wiring is never connected to the lighting circuits and it does not need to conform to the Underwriters' requirements for light or power wiring.

ANNUNCIATORS

40. When a number of push buttons are installed, it is convenient to have an indicating device to show from which button the bell is rung. This instrument is called an **annunciator**. An ordinary house style is shown in Fig. 10. On the face are rows of small windows, before one of which an indicator appears when the bell rings, showing from which room the signal has been sent. A handle *h* at

the side is intended to be used to restore the indicators to their normal position when the call is answered. A view of the indicator itself is given in Fig. 11. A hinged arm *a* carries a card bearing the name or number of the room to which the drop is connected, and is held up in the position shown by a counterbalanced trip *t* in front of an electromagnet *m*. As soon as the current passes through the electromagnet, the trip is attracted and the indicator falls, being then visible from the outside through one of the openings in the front.

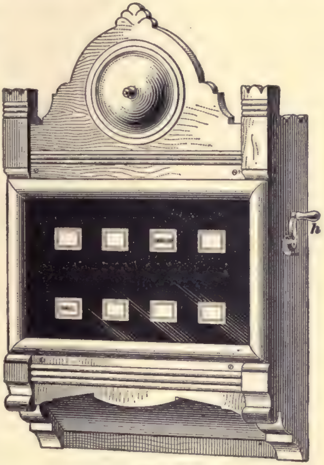


Fig. 10

41. The **needle annunciator,** Fig. 12, is a style much used in hotels and for elevators. The current on passing through the electromagnet of an indicator attracts a pivoted iron armature carrying a pointer *P* on the outside dial, causing it to set in an oblique position, in which it is held by a catch until released by pressing the knob *k* below the case. Annunciators can be obtained in almost any desired finish and for any number of drops. One type that has lately become very popular is the **self-restoring annunciator.** In the ordinary instrument, the drops must always be put back after a call comes in; sometimes this is not done, and consequently one is at a loss to

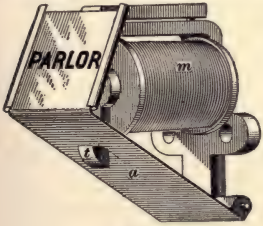


Fig. 11

know, when several are down, which button has been pushed. Self-restoring annunciators are constructed so that when a button is pushed its corresponding drop falls and remains down until the next call is sent in. This operates a magnet that moves the restoring device and resets the first drop. Self-restoring annunciators are somewhat more liable to get out of order than the simple kind and some of them require more battery power. They are, however, a great convenience, and are rapidly finding favor. They are wired up to the buttons in the same way as an ordinary annunciator, as the restoring device is wholly within the annunciator itself and therefore does not affect the outside connections.

FIG. 12

RUNNING BELL WIRE

42. There are no regulations governing the insulation used on bell wire. That generally used is known as *annunciator wire* and is usually No. 16 or No. 18 B. & S. copper-covered, with two wrappings of cotton treated with paraffin. This wire is cheap, but it is not moisture-proof, and the insulation does not adhere very firmly to the wire. However, it will work satisfactorily if it is carefully put up and is run in a dry place. For good work, *weather-proof office wire* or rubber-covered wire should be used. The insulation on the weather-proof wire is heavier than on the annunciator wire and adheres firmly; it is also damp-proof. If it is necessary to run bell wires where they will be exposed to considerable moisture, the best plan is to use rubber-covered wire.

The size of wire used is generally No. 16 or No. 18 B. & S. It will pay to use nothing smaller than No. 16, because the cost is very little more, the line resistance is thereby reduced, the batteries work to better advantage, and the line is mechanically stronger. For the main-battery wire in large installations, No. 14 may be used to advantage.

Bell wires are often stapled to woodwork, especially when bells are installed in old houses. If any stapling is done, care should be exercised not to drive the staples so hard that they cut through the insulation and break the wire. Do not fasten two wires down under the same bare staple; special staples, using a small saddle of leather between the wire and the top of the staple, are made for this work. When bell wires are run in new buildings, they may usually be run through holes in the beams, and they should be grouped together as much as possible. By doing this, the wires are run in an orderly manner and very little stapling is needed.

In the best class of work, bell wires are sometimes run in conduits, but no matter how they are run, all circuits should be carefully tested out after they are put up to make sure that there are no grounds, breaks, or crosses. See that all bell wires are kept well away from electric-light wires and that no push buttons are mounted in the same wall plate with electric-light switches.

BELL AND ANNUNCIATOR CIRCUITS

43. Fig. 13 shows a number of connections for simple bell circuits; for the operation of such circuits two or three cells will usually be sufficient. In (*a*), a single bell is operated from a single push button; (*b*) shows two bells operated in parallel from a single button; (*c*) shows two bells operated in series from a single button. When bells are operated in series, all but one of them should be made single stroke so that the interruption of the current will be performed by one bell only; otherwise, the bells will not work satisfactorily because one may open the circuit at the same instant that another tries to close it. View (*d*) shows one bell operated from either of two push buttons. Views (*e*) and (*f*) show two arrangements for ringing two bells from any one of three stations. Fig. 14 shows a plan of bell wiring suitable for a small dwelling where no annunciator is used.

Fig. 15 shows a method of controlling a bell from two stations by using two switches *a*, *b*. The bell can be rung

from either station independently of the position of the switch at the other station. Fig. 16 shows a method of controlling a bell from three stations. It is the same as Fig. 15 except that a four-point switch is cut in for the intermediate station. In one position, points *1, 2* and *3, 4* are connected, as shown, by the dotted lines. In the other position, points *1, 3* and *2, 4* are connected. The connections shown in Figs. 15 and 16 correspond to those used for

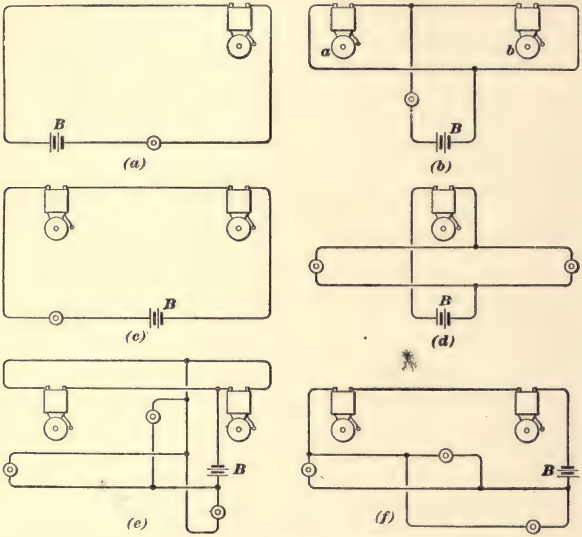


FIG. 13

the control of incandescent lamps from two or more points and by adding an additional four-point switch to Fig. 16 for each intermediate station the plan can be extended to any number of stations.

Placing bells in parallel requires a larger volume of current to be supplied than when they are in series, because the total current subdivides among all the bells. This calls

for a large battery and large wires. When the branch circuit containing one bell is very much longer, and hence of higher resistance than the branch containing another bell, the current will not divide equally between the two bells,

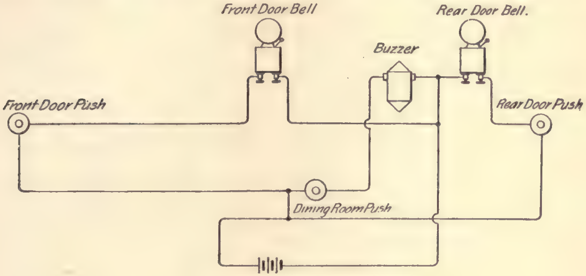


FIG 14

and hence the parallel arrangement may not be satisfactory in such cases. Placing the bells in series requires an additional cell or two, but no larger wire is needed.

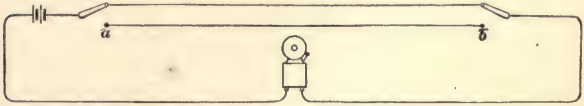


FIG. 15

44. Wiring for Simple Annunciator.—A wiring diagram for a simple annunciator system is shown in Fig. 17. The pushes *1*, *2*, *3*, etc. are located at convenient points in

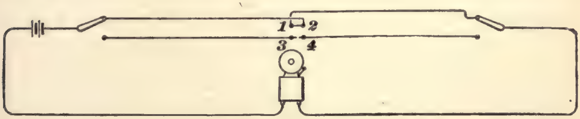


FIG. 16

the various rooms, one terminal being connected to the battery wire *b* and the other to the leading wire *l* communicating with the annunciator drop corresponding to that

room. The battery wire is run from one pole of the battery direct to one side of each of the pushes. The other side of each push is then connected to its drop on the annunciator. A battery of three or four Leclanché cells is placed at *B* in any convenient location, but should not be set in a dark or inaccessible spot or be exposed to frost.

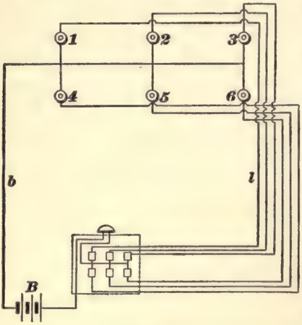


FIG. 17

45. Wiring for Return-Call Annunciator.—One of the many methods for connecting return-call annunciators is shown in Fig. 18. It requires one leading wire from each station to the annunciator and two battery connections to each station, as indicated by the branches from the heavy battery wires. The annunciator board is divided into two parts—the upper part having the bell and the numbered drops, and the lower the return-call push buttons. Each room is also provided with a double-contact push, such as is shown in Fig. 19. The tongue *t* makes connection normally with the upper contact *c*, but when pressure is put on the button *k* the tongue is forced against the lower contact *c′* and connection with the upper contact is broken. The return-call buttons on the lower part of the annunciator are of the same description. Assume, in Fig. 18, that the button in room *1* is pressed; current can then flow from the + side of the battery–annunciator bell–drop *1*–upper contact of button *1′*–tongue of button *1″*–negative side of battery by way of lower contact on *1″* since this button is supposed to be pressed down. This rings the annunciator bell and operates drop *1*. As soon as *1″* is released, the tongue makes contact with the upper point as indicated. To send the return, signal button on the annunciator *1′* is pressed, thus allowing current to flow from positive side of battery–bell

1–tongue of button *1″*–tongue of button *1′*–negative side of battery, since button *1′* is now pressed down. It will be noticed that a signal sent from a room to the office

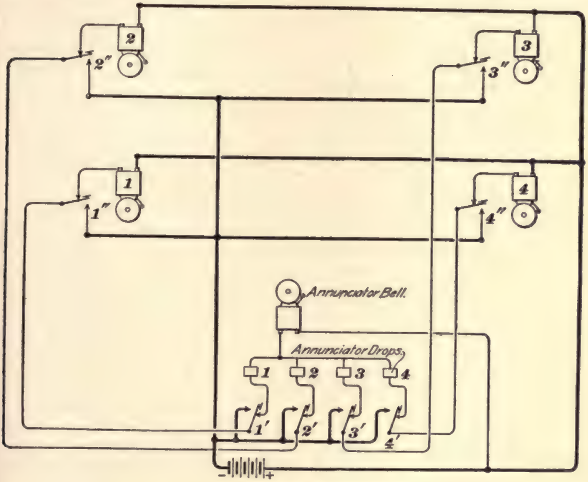


Fig. 18

does not ring the bell in the room but does operate the annunciator bell and drop. On the other hand, a call sent from the office operates the bell in the room but does not operate the annunciator bell or drop.

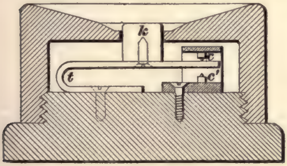


Fig. 19

46. Fig. 20 shows another method of wiring very similar to Fig. 18, except that two sets of cells are used. Battery *A* furnishes the current for sending signals from the rooms and *B* for sending signals to the rooms. The batteries must be connected with their polarities as shown, so that in case a push in one of the rooms and one at the annunciator

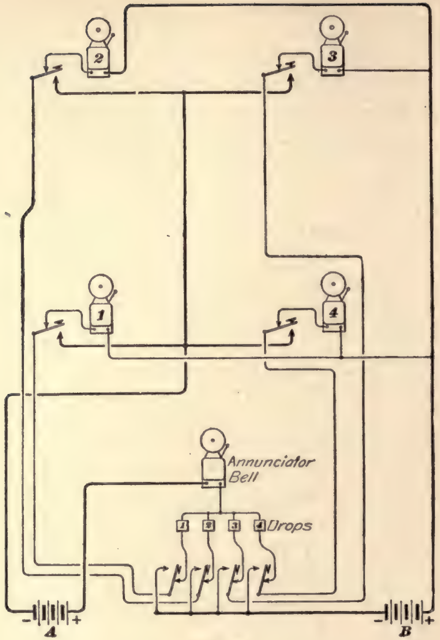

2
3
1
4
Annunciator Bell
1
2
3
4
Drops
- A +
- B +

FIG. 20

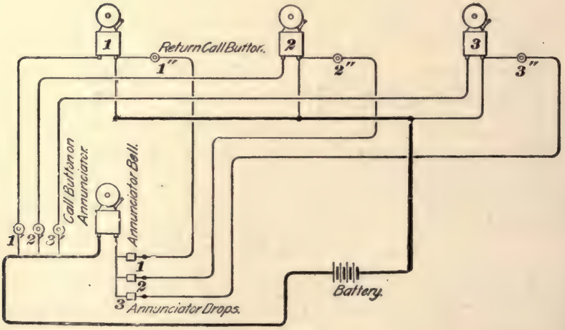

1
2
3
Return Call Button
1''
2''
3''
Call Button on Annunciator.
Annunciator Bell.
1'
2'
3'
1
2
3
Annunciator Drops.
Battery.

FIG. 21

should happen to be pressed at the same instant, the two sets of cells would oppose each other and would not cause all the drops and bells to operate. This scheme of connections is used with Holtzer-Cabot, and Partrick Carter and Williams annunciators, but those of either make can be connected as in Fig. 18 if desired. There is an advantage in having the cells separated into two groups because the sending signals in a certain installation may be more frequent than the return signals, or vice versa, and each set of cells can be kept in a condition suited to the work it has to do, independently of the other set.

47. Fig. 21 shows a third method of wiring a return-call annunciator. Here, there are two leading wires from each station to the office and only one battery wire is required. Ordinary push buttons are used. On account of the necessity of two leading wires for each station this plan would in most cases require somewhat more wire than that shown in Figs. 18 or 20.

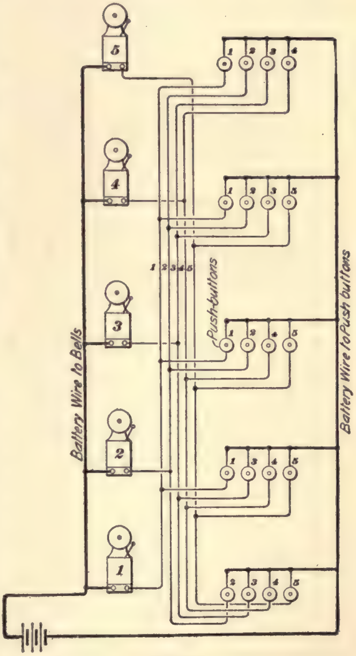


FIG. 22

48. Wiring for Speaking-Tube System.—Fig. 22 shows a plan of wiring frequently used in connection with speaking tubes. There are five stations with a bell and four

push buttons at each. Any bell other than the one at the calling station can be rung by pressing the corresponding button, and the bell at any given station can be rung from any of the other four stations.

49. Bell Wiring for Flats.—Fig. 23 shows a plan of wiring for door bells in flats. Four push buttons are placed at the main-hall entrance. Each flat is also provided with a push button at its front door and a second push button at the rear door. The rear-door button operates a buzzer so that a signal from it can be distinguished from a front-door signal.

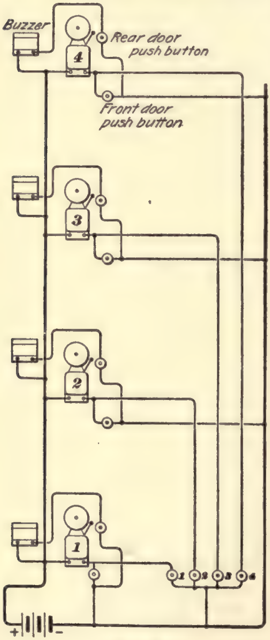


Fig. 23

50. Wiring for Fire-Alarm Gongs.—The wiring shown in Fig. 24 is suitable where fire-alarm gongs are installed. All the gongs ring when an alarm is sent from a station and an annunciator is placed at each station to indicate the point from which the alarm was sent in. If the switch at station *3*, for example, is closed, all three gongs will ring and drop *3* on each annunciator will indicate the point from which the alarm is sent. The dotted lines indicate another method of installing the battery. If connections *a*, *a*, *a* are omitted, batteries *b*, *b*, *b* placed at each station, and the main battery replaced by connection *c*, the system as a whole will be more reliable than if a single battery were used, because if one of the batteries fails it only cuts out of action the

corresponding bell and annunciator and the others continue to operate.

51. In installing annunciator systems, it is usual to run the battery wire, which is No. 14 or No. 16 annunciator wire, through the building at some central portion. If there are many rooms, it will be advisable to splice on a length of No. 18 wire to extend from the push in each room to the

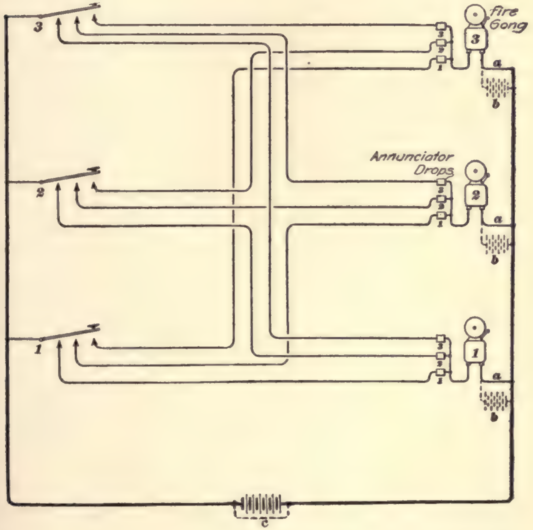


FIG. 24

battery wire. The connection from the other side of the push button to the annunciator, that is, the leading wire, should be No. 18. For the return-call system, a battery of four or five Leclanché cells is required.

All wires used in annunciator service should have distinguishing colors to prevent confusion. The battery wire may be blue, the return wire red, and the leading wires

white. This arrangement will greatly simplify the connections and reduce the liability of mistake.

52. Wiring for Elevator Annunciator.—The wiring for an elevator annunciator does not differ greatly from that of a simple annunciator; in fact, the scheme of connections is essentially the same. A battery wire *b*, Fig. 25, is run up the shaft and connected to each push button on the different floors. The return wires from each button are then carried to a point *a* at the middle of the shaft, where they should terminate in a small connection board, so that they may be readily disconnected from the wires in the cable running to the cage *e*. The wires running from the connection board to the cage are in the form of a flexible cable, which is made especially for this kind of work. This cable contains one more wire than there are push buttons, because it has to provide for the return wire *r*.

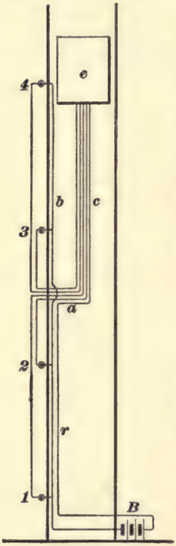
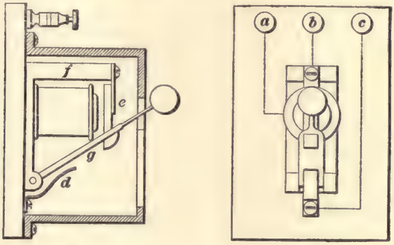


FIG. 25

SPECIAL APPLIANCES

53. The Automatic Drop.—For special alarm purposes, it is sometimes desirable that the bell should continue to ring after the push is released. This is accomplished by the use of an **automatic drop,** which closes an extra, or shunt, circuit as soon as a current passes along the main circuit. Fig. 26 shows two views of an automatic drop, *A* being a side elevation and *B* a front view with the cover removed. There are three terminals on the baseboard; those marked *a* and *b* are connected to the ends of the magnet coil, the end at *b* being also connected to the frame *f*; terminal *c* makes connection to the spring contact *d*, which is insulated from the frame and all other wires. The bell circuit is

closed first through *a–b* by means of the push button; the armature *e* is at once attracted, thereby releasing the rod piece *g*, which falls by gravity and makes contact with the spring *d*, establishing a circuit between *b* and *c*, which short-circuits the push button and magnet coil of the drop.



A B

FIG. 26

54. The connections for the automatic drop are shown in Fig. 27. The circuit obtained, on pressing the push button *p*, is from the positive pole of the battery *B* through the push to the terminal *a* of the drop, through the magnet coils to *b*, and then through the bell to the negative pole of the battery. As soon as *d* falls, the magnet coils are cut out, the current being diverted at *e*, and passes by way of the new contact from *c* to *b*, and thence through the bell and back to the battery.

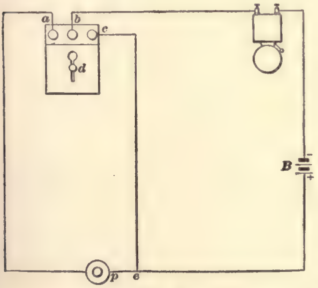


FIG. 27

Vibrating bells are sometimes made with a continuous ringing attachment that takes the place of the automatic drop. A small lever is mounted near the armature of the bell so that when the armature is attracted the lever is released by the movement of the armature and drops down, thus completing

the shunt circuit around the push button and allowing the bell to ring until the small lever has been restored to its normal position.

55. Two-Point Switch.—When two bells are arranged to ring from one push button, it is sometimes desirable to cut one of them out during some part of the day. For this purpose a small switch, Fig. 28, is used, by means of which one bell, when connected in series with the other, may be short-circuited. The wires are run to the back of the switch, one connection being to the lever arm at *a*, the other to the contact piece *b*.

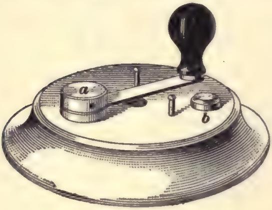


FIG. 28

56. Door Openers.—In apartment houses, banks, and other places it is often convenient to have the latch on a door arranged so that the door may be unlocked from some distant point. For this purpose **door openers** are used. These are made in a number of different styles, the mechanism differing with the different makes. In all of them, however, the unlocking is effected by means of an electromagnet, which is connected to the push and battery in the same way as an ordinary bell.

BURGLAR ALARMS

57. Automatic switches may be placed on windows and doors, in connection with alarm bells, to indicate when entrance into a building is being forced. There are three methods of installing these alarms—the open-circuit, the closed-circuit, and the combined open-and-closed circuit systems. In the **open-circuit system,** which is the one usually employed, the connections are similar to those of an ordinary electric-bell circuit, the automatic circuit-closing device being substituted for the push button. There are many different kinds of window springs made, one of which

is shown in Fig. 29. This is let into the window frame, the cam *c* alone projecting; when the window is raised, the cam is pressed in, revolving about the pin *p*, and makes contact with the spring *s*, which is insulated from the plate by a washer at the lower end and is normally prevented from touching the cam by an insulating wheel *w*. The wires from the bell and battery are connected to the plate and spring, respectively. The annunciator used is much the same as that employed for bellwork, but additional convenient attachments are usually placed on it, such as a device to keep the bell ringing until the annunciator is reset, a clock to connect and disconnect the system at certain hours, etc. The annunciator is usually equipped with a small button over each drop, which when pushed will complete the circuit and cause the drop to fall if there happens to be any door or window open. These are very useful for testing out to see if everything is closed. All these appliances belong to the annunciator itself and do not affect the general plan of wiring, which is carried out in the same way as for bell wiring.

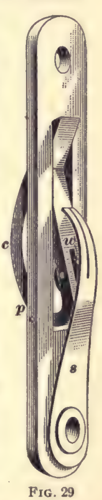


FIG. 29

58. Open-Circuit System.—In Fig. 30 is shown an ordinary annunciator, arranged to be used as a burglar alarm. During the day, when not in use, the switch *s* is placed on the intermediate, or open position, as shown. When closing the alarm for the night, a silent test is made by placing *s* first upon contact *a*, and closing the individual circuit switches k_1, k_2, one at a time; if any window or door on a circuit is open, the annunciator included in that circuit will allow its shutter to fall, but the bell will not ring. After all the windows, doors, and individual switches are closed, the switch *s* is placed upon contact *c*. If, during the night, any window or door, for instance in the hall, is opened, one of the contacts *e*, *e* in the hall circuit will be closed, and a current flowing through line *1* will cause the shutter of the annunciator a_1 to fall and the bell *v* to ring. With some

annunciators, the bell is arranged to ring continuously when once it is started. This may be done in various ways, one of which is indicated by the dotted lines in the figure, whereby a circuit through the bell v, resistance r, and battery B is closed when any shutter drops.

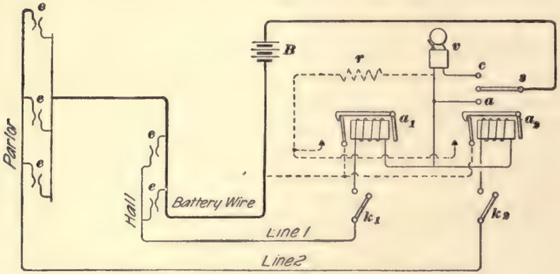


FIG. 30

59. Closed-Circuit System.—In Fig. 31 is shown a closed-circuit burglar-alarm system, so called because current normally flows through the various circuits, and the bell only rings when the circuit is opened. The current that flows normally through the various circuits from the

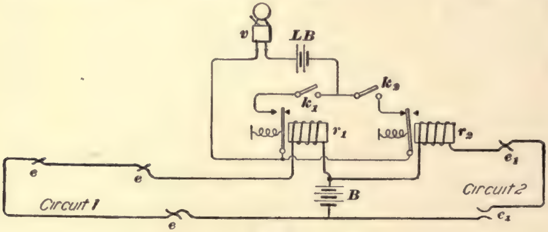


FIG. 31

battery B, energizes the relays r_1, r_2 and keeps the local bell circuit open. Should the circuit be opened by opening a door or window or by breaking a wire, as at e_1, the relay r_2 will release its armature and thereby allow current from the local battery $L B$ to ring the bell v, which will not stop until

the switch k_2 is opened, the relay circuit closed, or the battery *L B* gives out. In this system, the main battery *B* must be of the closed-circuit type because it has to furnish a small current continuously.

60. Open and Closed Circuit System.—Where a system is desired to give an alarm, whether the circuit is opened or closed at a window or door, or the wires broken or crossed at any point, the arrangement shown in Fig. 32 may be used. Two line wires are necessary; in line *N* are connected springs *c, c, c* normally closed, and between this wire and line *M* are connected springs *o, o, o* normally open. If the circuits are in good order, the alarm is set for the night by closing switch *w* and pushing the armature of the

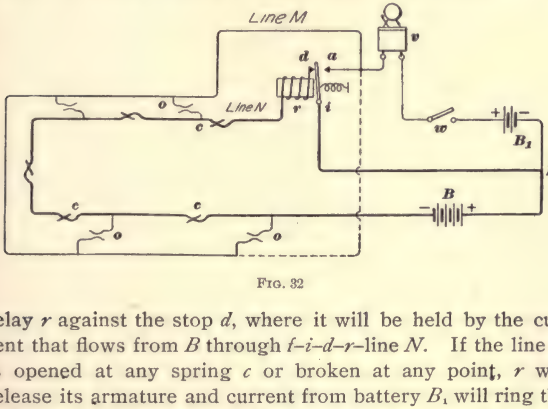


FIG. 32

relay *r* against the stop *d*, where it will be held by the current that flows from *B* through *f–i–d–r*–line *N*. If the line *N* is opened at any spring *c* or broken at any point, *r* will release its armature and current from battery B_1 will ring the bell *v* until *w* is opened. If any spring *o* is closed, current flowing through *w–v*–line *M*–any spring *o*–line *N*–battery *B*–battery B_1 will ring the bell. In this case, the two batteries are in series and must, therefore, be connected relatively as shown. The bell will also ring if lines *M* and *N* become crossed at any point. The dotted line is not necessary, but with it the system affords still better protection against tampering with the wires, for, if line *M* is broken anywhere,

either part into which it has thus been divided is still capable of sending in an alarm if crossed with line N at any point.

It is usual when connecting up burglar-alarm annunciators to group the windows or doors; i. e., the contacts on several doors or windows are connected in parallel and attached to one drop. To provide a drop for each door and window would require too large an annunciator and would cost too much for the ordinary run of work.

ELECTRIC GAS LIGHTING

BURNERS FOR PARALLEL SYSTEM

61. In the application of electricity to gas lighting, a spark is caused to pass between two conductors, placed near the burner, at the same time that the gas is turned on. In the **parallel system** of lighting, each burner is independent of all the others, having direct connection between the battery wire and ground. Three styles of burner are used—the *pendant*, the *ratchet*, and the *automatic* burner.

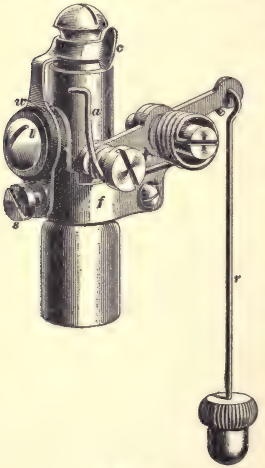


Fig. 33

62. The **pendant burner** is shown in Fig. 33. A well-insulated wire is brought to the burner and secured under the head of the screw s, thereby making connection to the stationary contact piece c, which is fastened by a screw l to frame f and insulated from it by washers w. On pulling pendant r downwards, spring a is drawn across c, and, on passing off at the upper side, the break causes a spark that, when the gas has been turned on, will ignite it.

63. The **ratchet burner** is very similar to the plain pendant, but is provided with a ratchet and pawl operated by a pendant, a downward pull turning on the gas at the same time that the spark is produced. A second pull extinguishes the gas.

64. The **automatic burner** is shown in Fig. 34 with the cover removed. Two wires must be provided, running from a double push button, one of them leading to the wire *a* and the other to *b*. The circuit from *a* is through the left-hand magnet coil *c* to the insulated band *d*, which has a projection *e* at one side. Upon this rests a metal rod *r*, bent at the upper end and terminating in a contact piece; at the lower end the rod is grounded by connection with the frame *f*. Each magnet coil has an armature *g* or *g'* with a projecting finger on the inner side. When current is sent through the magnet *c*, the armature *g* is raised and turns the gas valve *v* by striking one of the pins. At the same time the rod *r* is pushed up, thus breaking the circuit at a point where the gas is escaping and producing a spark that will ignite it. To provide for certain action, the sparking should continue longer than the instant of turning on the gas; this is effected by the use of a spring to restore the circuit. The rod is forced upwards against the spring *s*, but when the circuit is opened at the spark gap, the spring presses the rod and armature down again, and the circuit being thereby closed, a spark is again produced on opening. This continues as

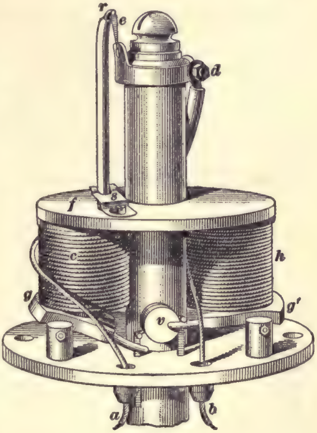


FIG. 34

long as the push button is pressed, the action being similar to that of an electric bell. The second coil *h* is grounded at the inner end, and when a current is sent through, the armature *g'* is raised, turning the valve and cutting off the supply of gas. Automatic burners are convenient where it is wished to light or extinguish a gas jet from some distant point, but they are not very safe because of their liability to leak gas. They are used principally in hallways where it is desired to light or extinguish the gas from any floor.

ARRANGEMENT OF LIGHTING APPARATUS

65. To light gas by electricity, a spark of considerable intensity must be produced. This can be done by means of batteries and induction coils or by an electrostatic discharger. For the parallel system used with the burners just described, a **spark coil** is employed to supply a good spark. Fig. 35 shows an ordinary spark coil which is made up of an iron core about $\frac{3}{4}$ inch in diameter and 8 inches long, built up out of soft-iron wire and wound with five or six layers of No. 18 magnet wire. The coil *k* is connected in

FIG. 35

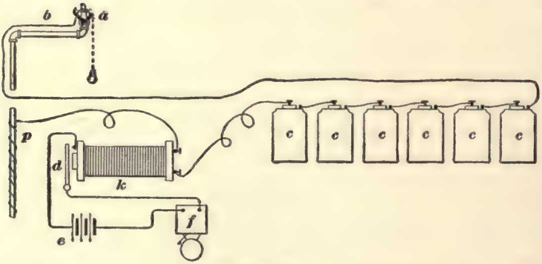


FIG. 36

series with the cells *c*, as indicated in Fig. 36. The battery should have at least six cells for satisfactory service. One end of the coil is connected to the gas pipe *p*. When the

pendant is pulled, the tip makes contact and a current is established through the circuit. When the circuit is broken, the self-induction of coil *k* causes a bright spark at the break. In case a ground occurred on the wiring, there would be a steady flow of current from the battery which would soon run it down. To give notice of such current leakage, the spark coil can be provided with an armature *d* that will be attracted by a steady flow of current in *k* and thus allow current from the local battery *e* to flow through bell *f*, giving a signal. The momentary current that flows in *k* whenever a burner is lighted would not usually flow long enough to

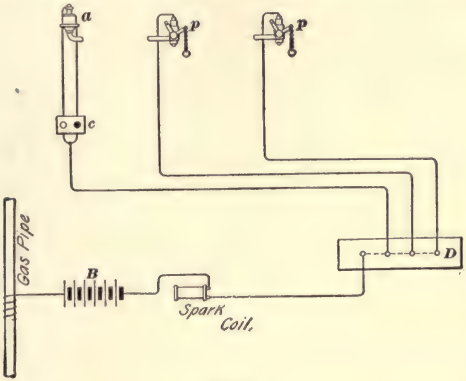


FIG. 37

attract *d*. In more expensive installations, separate wires are run for both sides of the circuit and the gas pipe is not used as one side.

66. The wires are usually run on the outside of the gas fixtures, but they may be concealed, if there is sufficient room, between the fixture shells and the gas pipe. It is advisable to use wire provided with good insulation, for grounds on the fixtures are liable to occur. Where fixtures are wired on the outside, the wires should be painted or made with the proper colored insulation, so as not to show;

but they must not be painted with bronze or metallic paint, which would penetrate the insulation and cause grounds, unless rubber-covered wire were used.

67. To make the location of grounds easy, it is advisable to run separate wires from a distributing point near the battery to each fixture or group of fixtures. The wires can be connected together at that point by means of a connecting board, at which any fixture can be disconnected. This makes the location and removal of grounds an easy matter. Fig. 37 shows the general arrangement of a system using both plain pendant and automatic burners. The distributing board is shown at *D*. The automatic burner is provided with a double push button *c*. When the dark button is pressed, the light is extinguished; when the light button is pushed, the gas is turned on and lighted.

The Underwriters' rules now prohibit the use of electric gas lighting on combination fixtures that are also equipped with electric light. There is too much danger of the gas-lighting wiring coming in contact with the electric-light wiring. Moreover, where there is electric light on a fixture there is little need for electric gas lighting because at best, the only excuse for electric gas lighting is that it makes gas nearly as convenient as electric light so far as turning the light on and off is concerned. Electric light has now replaced gas to such an extent in hotels, theaters, churches, and other public places, to say nothing of private houses, that electric gas lighting appliances are going out of use. These outfits are a continual source of annoyance, unless they are kept in good condition and they are specially liable to get out of order in private houses where they are not, as a rule, properly attended to.

APPARATUS FOR SERIES LIGHTING SYSTEM

68. The **series, or flash, system** of gas lighting is used in large halls, churches, theaters, etc., where many lights are installed in groups. A fixed spark gap is used at each burner, both of the points being insulated from each other and from the gas pipe, except the last point of a series, which is grounded. The style of burner used is shown in Fig. 38, in which *a* and *b* are the points of the spark gap. To complete the connection between consecutive burners, a fine bare copper wire, about No. 26 gauge, is stretched across, being secured through the small holes at the lower ends of the strips *a*, *b*. The body of the burner is made of some insulating substance, and a flange of mica *m* is added to give further protection.

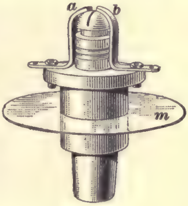


FIG. 38

Since one circuit may consist of a number of burners, it will be seen that the E. M. F. must be very high to force a current across so much air space, and to insure success, the wiring must be installed with the greatest precaution. The wire should nowhere be nearer to the gas pipe than $1\frac{1}{4}$ inches; if, however, it is necessary to approach more closely, the wire

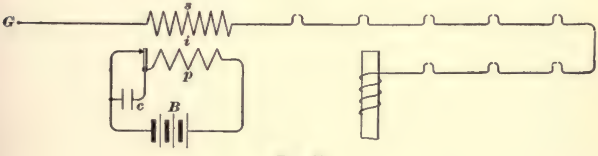


FIG. 39

should be enclosed in glass tubing. A coil giving a 1-inch spark can light a circuit of about 14 or 15 burners.

The apparatus required for this system of gas lighting consists of an induction coil *i*, Fig. 39, operated by a battery *B* and used with a condenser *c* across the spark gap of the primary *p*. The condenser cuts down the spark at the

circuit-breaker, for this spark would be very destructive in the case of a large coil. The fine-wire secondary *s* is grounded at *G*, and the other terminal is connected to the line wire passing to the burners.

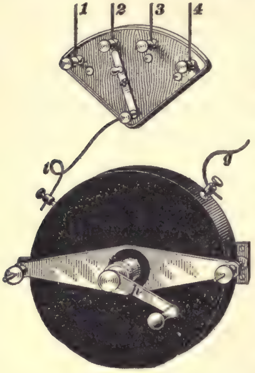


Fig. 40

69. Frictional machines are also used in the series lighting system. These generate static electricity, and in many cases are more reliable than induction coils, as there is no battery to get out of order. One form of this machine is shown in Fig. 40. One of the terminals *l* is to be connected to the switch handle *s* and the other *g* to ground. The machine is rotated by means of the handle *h*, and the switch is moved from one contact to the next, lighting the gas on each circuit *1*, *2*, *3*, *4* in rapid succession.

MERCURY-VAPOR CONVERTERS

DEFINITIONS AND PRINCIPLES

1. As an aid in studying the following pages, a few of the terms most commonly used will here be briefly defined and illustrated. Many of these terms have already been mentioned in other Sections.

A **direct current** is a unidirectional current; that is, one that does not change in direction of flow, although it may change in value or amount. Direct currents are produced by voltaic cells, dynamos, etc.

A **pulsating current** is a direct current that consists of distinct and regular impulses; it may be likened to the flow of blood from the heart—always in the same direction, but in rhythmical beats, or throbs.

A **continuous current** is a steady non-pulsating direct current. Either a pulsating or a continuous current may vary in value; for example, either may be, say, 50 amperes at one moment and may rise to 75 amperes or drop to 25 amperes at the next moment, as the load conditions vary.

2. An **alternating current** is one that periodically reverses in direction, flowing to and fro in a conductor with as great regularity as the piston of a steam engine moves to and fro in a cylinder. Alternating currents are produced by machines called **alternators.** An alternating current passes through continually recurring series of changes called **cycles;** the cycles follow each other in rapid succession. The number of cycles per second is called the **frequency,** and the length of time required to complete one cycle is called a

period. Alternating currents are in commercial use at frequencies varying from 25 to 140 cycles. Frequencies of 25 or 30 are becoming quite common for transmitting electric energy, but frequencies of 40, 50, and 60 are considered more suitable for lighting purposes. The higher frequencies above 60 to 80 are less used than formerly.

A better idea of a cycle may be obtained by conceiving one of the series of changes to be made very slowly. Suppose, for example, that at a given instant the current in a conductor is zero, that is, no current is flowing. Imagine that a very small current begins to flow in one direction, which may be called positive, and that this current gradually increases to a certain value, which may be called maximum positive, and then gradually decreases to zero; also, that immediately a small current begins to flow in the opposite, or negative, direction, increases gradually to maximum negative, and decreases again to zero. This completes one cycle, or 360 electrical degrees, the next change being to increase again in the positive direction, as at first. Each time the current passes through zero value it reverses in direction; each cycle, therefore, contains two reversals, or **alternations.**

3. Phase Relation.—Two alternating currents are said to be in **synchronism** when they have the same frequency; they are in **phase** when in synchronism and when they pass through corresponding values of their cycles at the same instant. Strictly speaking, they may be in synchronism without being in phase, but common usage now makes the word synchronism include the idea of phase also. With this meaning, two engines may be said to be in synchronism when they not only run at the same speed, but when their strokes begin and end exactly together.

A single alternating current flowing in a system of conductors is called a **single-phase current.** Two alternating currents in a system, differing from each other in phase by one-fourth cycle, or 90°, make a **two-phase, or quarter-phase, system.** Three alternating currents in a system,

differing in phase from one another by one-third cycle, or 120°, make a **three-phase system.** All alternating currents having more than one phase are called **polyphase currents.**

4. The **electrodes** of an electric appliance are the terminals by which the current is led into and out of it. The **anode** is the electrode by which the current enters, and the **cathode** is the electrode by which the current leaves.

5. An **electric,** or **voltaic, arc** is a bow of very hot luminous flame in the air space, or gap, across which an electric current is passing between two electrodes. Whenever a circuit in which a current is flowing is broken, an arc is formed; and if the gap between the ends of the broken circuit is not too long, the arc may be maintained continuously or until it is purposely suppressed by blowing it out by means of a jet of air or a magnet brought near it, or by stopping the current flow in some other way. After the arc has been suppressed, the same pressure that maintained it cannot reestablish it; in fact, before the arc can be reestablished, the pressure across the gap must be made very much higher or else the gap must be shortened. When the arc is established, the intense heat vaporizes a portion of the material of the electrodes, and the vapor acts as a conductor across the gap.

6. A **storage battery, secondary battery,** or **accumulator,** as it is variously called, is, as its name implies, a device for storing electricity. It consists of several cells, each containing plates of metal, or metallic compounds, immersed in an electrolyte that acts chemically on the plates when an electric current is passed through the electrolyte from one plate to another. This action leaves the plates in such a condition that they are said to be *charged*, and when the source of the charging current is removed and the plates are connected outside the electrolyte, a discharge current will flow through the outside connection, passing from plate to plate through the electrolyte in a direction opposite to that taken by the charging current. Storage batteries are

used for operating electric vehicles, telephones, bells, etc., as well as in large power plants for storing electricity when there is small outside demand for it and for supplying it when the demand is great.

7. An **autotransformer** is a transformer having but one winding, which serves for both the primary and the secondary coils. Fig. 1 shows the general arrangement: A represents the laminated iron core on which are wound two coils t, t' connected in series, so that they practically form one coil. The primary line wires are connected to the terminals a, b, and the secondary line wires to a, c. The ratio of the secondary pressure E_s to the primary pressure E_p depends on the ratio of the number of turns t' to the total number of turns between a and b, or $t' + t$. For example, if t' is one-third the total number of turns, the voltage E_s will be about one-third the line voltage, and the current flowing in the secondary lines will be about three times that drawn from the primary line wires. Autotransformers are frequently made so that the secondary terminals may be connected to points located anywhere along the whole winding.

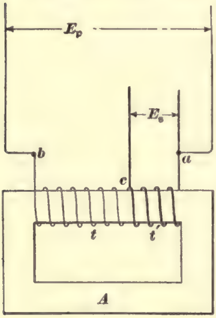


FIG. 1

8. A **vacuum,** strictly speaking, is a space wholly devoid of matter. As commonly understood, a vacuum is a space from which the air has been almost wholly exhausted, or removed; the greater the degree of exhaustion, the more nearly perfect is the vacuum. It is practically impossible to produce a perfect vacuum.

THEORY AND OPERATION

THEORY

9. A **mercury-vapor converter,** or **mercury-arc rectifier,** is a device for converting, or rectifying, alternating current to direct current; it has no rotating parts. This device consists essentially of a sealed glass vessel containing a small quantity of mercury and having the necessary electrodes sealed in the walls of the glass chamber. The air is exhausted as completely as possible from the interior of the vessel, leaving very nearly a perfect vacuum, except for the presence of mercury vapor. The Cooper Hewitt Electric Company make such a device and call it a *mercury-vapor converter*, while the General Electric Company call a similar device made by them a *mercury-arc rectifier*. The name *mercury converter* will be used in the following pages to refer to either, indiscriminately.

Of the two kinds of current, direct and alternating, either has uses for which it is much better adapted than the other. For charging storage batteries, for operating some types of arc lamps, and for electroplating, direct current is essential —alternating current cannot be used. For operating small motors, or any motors that must start frequently under heavy load or that must be capable of having their speed varied considerably, direct current is considered preferable, though alternating current can be used. But for transmitting electricity over long distances, alternating current, on account of the ease with which its pressure can be transformed up or down, is nearly always used.

Mercury converters, being free from rotating parts, require less attention, and moreover, in the small sizes in which they are usually made, they are more efficient than motor-generators or rotary converters of corresponding capacities;

hence, for charging small storage batteries, especially those used in automobiles and for telephones, as well as for supplying direct current to a type of arc lamps that requires it, mercury converters find extensive use.

10. To explain the action of a mercury-vapor converter, reference is first made to Fig. 2, which shows a closed glass tube *d*, into the ends of which are sealed wires that lead to a battery *b*. Inside the tube the wires terminate in electrodes *a* and *c*. The anode *a* may be either iron or graphite, while the cathode *c* is mercury. The air is exhausted from the tube.

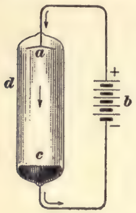


Fig. 2

If by some means an electric arc is started from the anode *a* to the cathode *c*, current will flow in the direction indicated by the arrows. To start the arc requires either that the difference of potential between the anode and the cathode be raised to an excessive value, perhaps 25,000 volts, or that the tube be shaken or tipped until the mercury forms a continuous stream between the two electrodes, and then righted again to break the stream. As soon as the stream is made continuous, the current follows it, and then when the stream breaks, an arc is formed. The heat of the arc immediately vaporizes some of the mercury, and the vapor reduces the resistance of the path between the two electrodes sufficiently to allow the maintenance of an arc and, therefore, the flow of current from the anode *a* to the cathode *c*. As long as the current flow is not interrupted, a comparatively low voltage will maintain the arc. The voltage required depends on the length of the arc and not on the strength of the current; that is, in a given tube the voltage across the arc will remain practically constant, even if the current strength varies. This may be explained by assuming that the greater the quantity of current, the more rapid is the formation of mercury vapor; hence, the greater is the conductivity of the path between the electrodes. In all such devices, the formation of mercury vapor occurs at the cathode.

With apparatus arranged as shown in Fig. 2, and with sufficient condensing surface, an arc once established will continue as long as the necessary electric pressure is maintained between the electrodes; but if the arc is allowed to cease, even for an instant, it will not start again unless either an excessively high voltage is applied or the tube is shaken or tilted until the stream of mercury is momentarily continuous between the electrodes.

11. Another theory advanced by some investigators is that the conductivity of the path depends not on the amount of mercury vapor present, but on the quantity of vapor that is decomposed or broken up by the action of the arc into infinitesimal electrified particles called *ions;* that is, that it is only the *ionized* vapor that is a conductor. This theory is not fully accepted and need not be further considered in this discussion. It is a fact, however, that the presence of too much vapor will smother the arc. The vapor condenses on the walls of the vessel and runs down to the bottom; and if the vessel is not large enough to afford sufficient condensing surface, the vapor soon becomes so dense that the arc goes out.

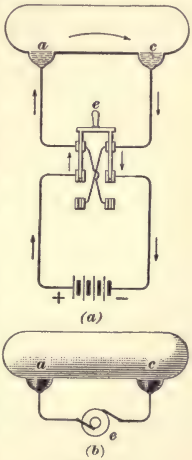


FIG. 3

12. If a tube were arranged with two mercury electrodes, as shown in Fig. 3 (*a*), and a reversing switch *e* were installed between the battery and the tube, an arc could be started by tilting the tube when the switch is in either position. For example, with the switch in the upper contacts, the direction of the current would be as indicated by the arrows; but any attempt to reverse the direction of the current by throwing the switch over to the other contacts, no matter how quickly it may be done, will cause the arc to go out, for there is an instant when the current is zero.

If a single-phase alternator *e*, Fig. 3 (*b*), is substituted for the battery and switch, the intervals in each current cycle, short as they are, during which the current is zero, are sufficient in duration for the production of the conducting vapor to cease and for the arc to go out. For instance, it has been determined that, even with a 10,000-cycle alternating current, which gives 20,000 reversals per second—a frequency far beyond any used in commercial work—the reversals are not quick enough to maintain the arc. No ordinary commercial single-phase alternating current will therefore support an arc with this arrangement of electrodes and tube.

13. A very small supply of the conducting vapor, if maintained continuously, will afford a conducting path for the arc. For example, if a tube has three mercury electrodes with a battery and a single-phase alternator connected thereto, as shown in Fig. 4, a small continuous current maintained by the battery *b* through the path *h–d–c–g* will be sufficient to enable the alternator to start an arc from *a* to *c*, sending current through the path *f–a–c–g*. However, an arc cannot be started between the alternator terminals *a* and *c* in the reverse direction; that is, it must always start so that the cathode of the continuous current will be the cathode of the alternating current. The device then acts as a valve that allows the current from the alternator to pass readily in one direction, but will not allow it to pass in the other.

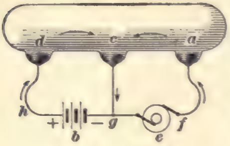


FIG. 4

14. An alternating current is made up of equal half waves, or impulses, in successively opposite directions, and may be represented by a curved line, as in Fig. 5 (*a*). For convenience, each pair of successive half waves, forming a cycle, may be called positive and negative, respectively, as indicated above and below the line of zero current *O–O'*. As the device shown in Fig. 4 will allow current from the alternator to pass in but one direction, only every alternate half wave can pass, and the current from *a* to *c* is as

represented in Fig. 5 (*b*); that is, only one-half the current is allowed to pass, the negative half waves being suppressed.

15. Fig. 6 shows an arrangement by which the negative half waves of an alternating current can be madé to flow in the same direction as the positive half waves; in other words, the alternating current is rectified and the entire current used. The tube has four electrodes: *a*, *a'* are the anodes to which the wires from the dynamo *e* or a transformer are connected; *c* is the cathode; and *d* is an auxiliary anode through which current enters the tube from a battery *b*.

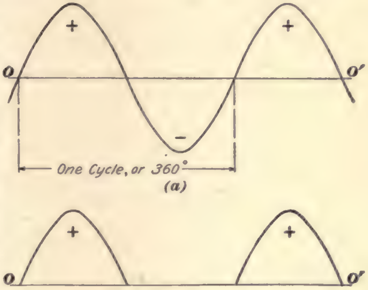


Fig. 5

The action is started by tilting the tube until the mercury forms a stream between the two electrodes *d*, *c*, so that the current from the battery can follow the mercury from one electrode to the other; then the tube is righted to break the continuity of the mercury stream. An arc is thus immediately formed from *d* to *c*, which maintains the supply of conducting vapor. Impulses of one polarity then flow from the source of alternating current *e* through *l–a–c–g–k–h–f–e*, and impulses of the opposite polarity through *f–a'–c–g–k–h–l–e*. Thus, current flows only in one direction through *g–k–h*, in which circuit may be located direct-current devices as represented

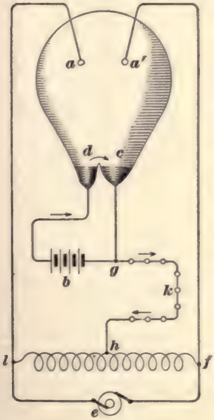


Fig. 6

by the circles. Comparatively little of the alternating current flows from *l* to *f*, or vice versa, on account of the high impedance of this whole coil.

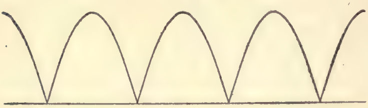


FIG. 7

The direct current thus obtained from the alternator is of a pulsating character and may be represented by the curve in Fig. 7. The negative half waves are reversed, or rectified. The direct current represented by this curve will not maintain the arc without an exciting current, such as is supplied by the battery, Fig. 6, for at the end of each half wave the pulsating current falls to zero.

16. Single-Phase Converter. Fig. 8 shows an arrangment by which the arc may be maintained by single-phase alternating current only, no battery being required. A choke coil *l* is connected in the direct-current circuit between the cathode *c* and the middle point *h* of an autotransformer coil. The choke coil delays each successive impulse of current until the next impulse from the other electrode has started; that is, it makes each direct-current impulse lag so that the half waves overlap one another, as shown by the dotted lines in Fig. 9. Because of its effect in sustaining the arc, the choke coil is frequently called the *sustaining coil*.

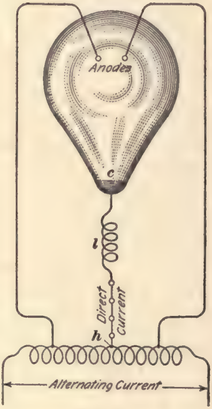


FIG. 8

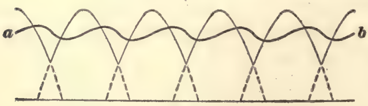


FIG. 9

The direct current from *c* to *h*, Fig. 8, at no time falls to zero, but consists of a series of slight impulses, as

represented by the full-line curve *a b* along the top portion of Fig. 9. The current could be made more nearly continuous than that represented by the line *a b* by increasing the inductance of the coil *l*, Fig. 8. For most purposes, a direct current having slight pulsations is not objectionable, but for charging storage batteries while supplying current to central-energy telephone systems, the pulsations should be smoothed out as much as possible.

OPERATION

STARTING

17. One of the greatest difficulties to be overcome in any device making use of an electric arc is that of starting the arc. Starting may be done by using an electromotive force high enough to make an arc jump across the gap; or, by first establishing a complete circuit and then, when the current has begun to flow, breaking the circuit, when the current will arc across the gap. Both methods have been used for starting mercury converters, but the one employed in all practical work is to bridge the gap between electrodes with a conductor and then break this bridge after the current has begun to flow. The same thing could be accomplished by bringing the electrodes together, as is done with the ordinary carbon arc for lighting purposes, and then separating them after the current flow has begun.

A very common method of starting the mercury-vapor arc is to tilt or shake the vessel until the mercury momentarily forms a bridge between an anode and the cathode; as soon as this bridge breaks, an arc starts and the production of the conducting vapor begins. A very small difference of potential between any anode and the cathode will then cause current to pass continuously, provided there is no instant when the current through the cathode becomes zero. For starting purposes, the tubes in commercial use for mercury converters have an auxiliary mercury anode on each tube near the cathode.

COOPER HEWITT MERCURY-VAPOR CONVERTER

18. Simplified Diagram of Connections.—The operation of the **Cooper Hewitt mercury-vapor converters** made for charging storage batteries will be explained with the aid of the simplified diagram of connections shown in Fig. 10. By comparing this figure with Figs. 12 and 13, the actual location of the various parts and their connections may be readily seen.

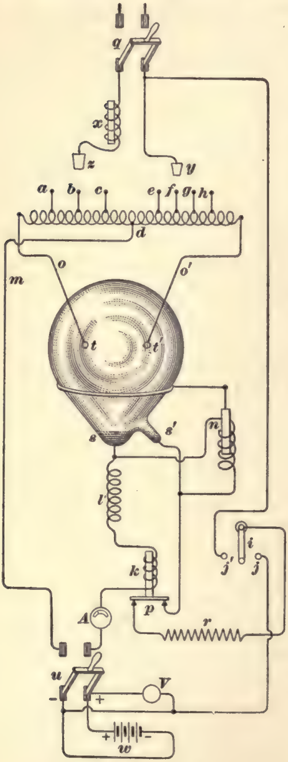


FIG. 10

If the direct-current load is a storage battery, which is commonly called a *live load*, the converter is started by turning the switch lever *i*, Fig. 10, to the right-hand contact *j* and closing both the alternating-current and the direct-current switches *q*, *u*. Current then flows from the positive terminal of the storage battery *w* through the ammeter *A*–cut-out magnet *k*–sustaining coil *l*–tilting magnet *n*–cut-out switch *p*–starting resistance *r*–starting switch *i*–*j* to the negative terminal of the battery. On account of the resistance *r*, this current is too weak to operate the cut-out magnet *k*. The tilting magnet, however, tilts the bulb until the mercury connects the two electrodes *s*, *s'*; the current then flows through the mercury instead of through the tilting magnet,

which is thereby so weakened that the bulb falls back to its upright position, thus breaking the stream of mercury between s, s' and therefore starting an arc from s to s'. The arc is at once picked up by one of the main anodes t, t', the current at first passing from the anodes to the cathode s', but the high resistance of the arc between s and s' causes the bulb to be tilted again almost immediately, and the arc is transferred to the main cathode s. The current is then forced back through the sustaining coil l, cut-out magnet k, and the ammeter to the storage battery from which the returning current flows to the neutral point d of the transformer. The current through the cut-out magnet k is strong enough to open the circuit through r and s'. The main voltage regulation for the direct current is obtained by placing the plugs z, y in connection with suitable taps a, b, c, e, f, g, h located along the autotransformer coil; the voltage with these plugs in any position may be further varied somewhat by changing the position of an iron core in the regulating coil x, which varies the impedance of the coil. The plugs y, z are different in size so that z can only be placed in a, b, and c, and y in e, f, g, and h. When the apparatus is in operation, both the resistance r and the tilting coil n are cut out.

19. Construction of Converter.—The Cooper Hewitt standard mercury-vapor converter made for charging storage batteries consists of a *bulb*, or the converter proper; a *panel* and *frame* with auxiliary parts, and an *autotransformer*.

The **bulb** is an exhausted glass vessel about 9 inches in diameter containing the electrodes, the most commonly used form being pear-shaped, as shown in Fig. 11. The auxiliary or supplementary starting anode is shown at s'; the cathode at s; and the anodes, almost completely enclosed in bottle-shaped glass vessels, at t, t'. These vessels hinder the formation of arcs between the anodes t, t', and openings near the bottoms opposite the anodes permit arcs to pass from the anodes to the cathode s. The anodes for converters up to 10 amperes capacity are made of iron; for higher capacities carbon is used.

All wires leading into the bulb are sealed air-tight in the glass walls, and after inserting the mercury for the cathode and the starting anode through a glass tube in the top of the bulb, the air is exhausted from the bulb and the tube is sealed, leaving a tip on the end of the bulb. The bulb is large enough so that the surplus vapor condenses on the inside and runs back to the electrode in the bottom. The terminals o, o' are used for connecting to the alternating-current supply circuit.

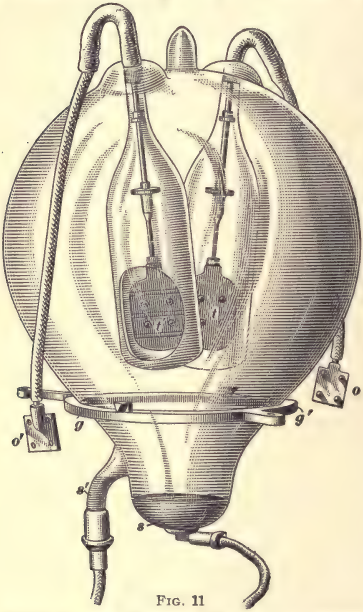


Fig. 11

When assembled in its frame, the bulb rests in a ring g, g' supported on knife edges, so that when the starting switch is closed, the bulb is automatically tilted by the tilting magnet until the mercury in the starting anode comes in contact with that at the cathode. The tilting magnet is short-circuited by the mercury stream, the bulb rights itself, tilts again. the arc starts, and the cut-out switch opens.

20. Panel and Frame.—Fig. 12 shows the complete standard type PA converter, including the front of the panel and the cage used to enclose the apparatus. The cage occupies a space 15 in. × 22 in. and is 22 inches high. The output of this converter is from 6 to 30 amperes direct current at any voltage from 50 to 115.

On the front of the marbleized-slate panel are mounted a direct-current voltmeter *V*; a direct-current ammeter *A*; a regulator handle *x* that turns a worm-wheel, to move a plunger or core in or out of the regulating coil connected in the alternating-current supply circuit; a switch *q* in the alternating-

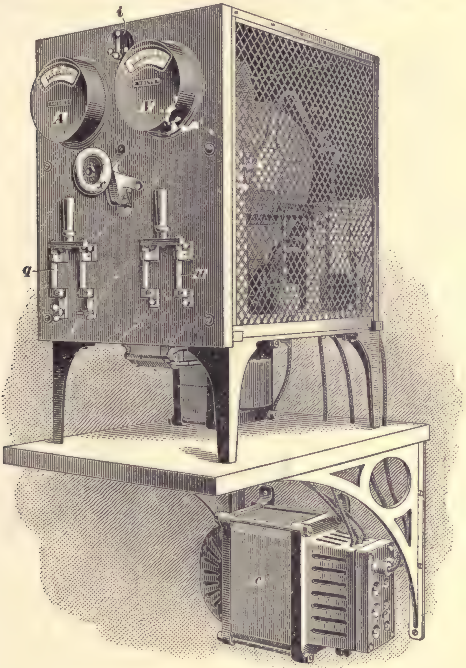


FIG. 12

current circuit; a switch *u* in the direct-current circuit; and a three-way starting switch *i*. Fig. 13 shows the back of the panel and the apparatus with the cage removed. On the back of the panel are the terminals of the instruments and switches and the starting resistance *r*, which is wound on porcelain tubes.

21. The panel, as shown in Fig. 13, is supported on a cast-iron frame. This frame also carries the supporting mechanism for the bulb; the regulating coil *x*, the core of which is moved by means of the hand wheel on the front of the board; the tilting magnet *n*; the sustaining coil *l*, for steadying the direct current and causing the necessary lag

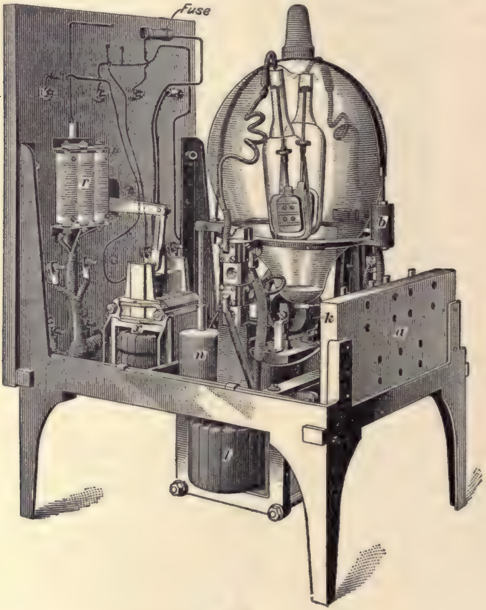


FIG. 13

of the rectified impulses; the cut-out magnet *k*, and a connection board *a*, having lugs for seven circuits or fourteen wires. A weight *b* helps to return the bulb to the vertical position after it has been tilted.

Under the table, or bench, on which the iron frame stands, is shown the autotransformer *c*, Fig. 12, with a plug board *e*

attached and into which two of the wires from the connection board *a*, Fig. 13, may be plugged. Five wires are connected to the autotransformer; these, with the two alternating-current supply wires, constitute seven of the wires leading to the connection board. The other seven, connected with those on the board, lead to various parts of the converter apparatus. The framework supporting the converter, instead of being cast with supporting legs as shown, may be provided for bolting to a wall, and the autotransformer may be placed at any convenient point near by.

22. Complete Diagram of Connections.—Fig. 14 is a diagram showing the principal parts of the converter laid out in a horizontal plane and also showing the connections. The anodes are connected to lugs *15* and *16*, the starting electrode to lug *21*, which is connected to lug *19*, and the cathode to lug *22*, which is connected to lug *20*. The alternating-current wires are connected through suitable fuses to lugs *1* and *2* on the connection board, and these lugs are connected to lugs *8* and *9*, respectively; the path of the alternating current may be readily traced to the alternating-current switch on the switchboard. When this switch is closed, one side of the alternating-current circuit is connected through the switch to lug *10*, and the other side through the switch and the regulator *x* to lug *11*. Lugs *10* and *11* are connected, respectively, to lugs *3* and *4*; and from the latter extend flexible leads terminating in plugs *y*, *z* that may be inserted into various holes in a plugboard attached to the autotransformer, according to the voltage transformation desired. Lugs *15* and *16* are connected, respectively, to lugs *12* and *14*, which, in turn, are connected to lugs *5* and *7*. From lugs *5*, *6*, and *7*, wires o', m, and o extend to the transformer, o, o' being connected to the extreme ends of the transformer coil and m to the middle, or neutral, point. Lug *13* is connected to lug *6* and also to the direct-current switch on the switchboard.

The two lower terminals of the direct-current switch are connected to the load—which may be a storage battery, a

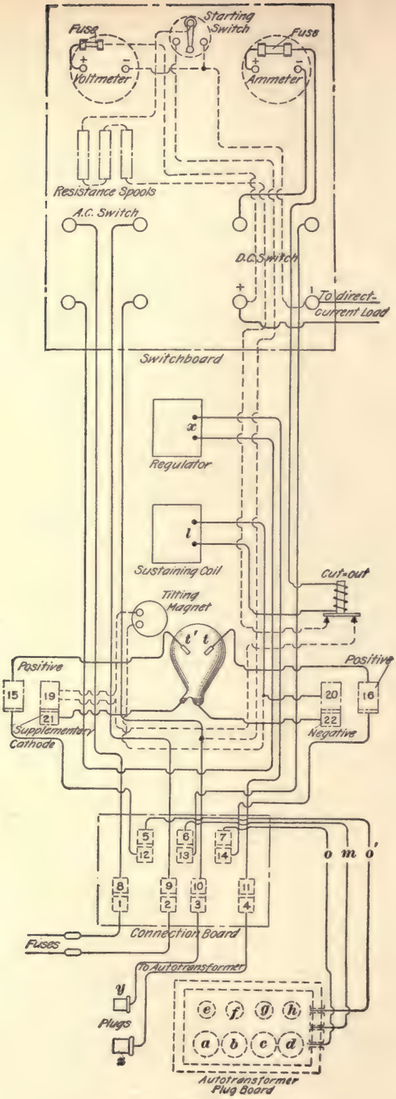

Fuse
Starting Switch
Fuse
Voltmeter
Ammeter
Resistance Spools
A.C. Switch
D.C. Switch
To direct-current Load
Switchboard
Regulator
Sustaining Coil
Cut-out
Tilting Magnet
Positive
Positive
Supplementary Cathode
Negative
Connection Board
Fuses
To Autotransformer
Plugs
Autotransformer Plug Board

FIG. 14

motor, or lights—and also to the voltmeter, so that if the load is a storage battery, its voltage may be read before closing the switch. One terminal of the ammeter is connected to the direct-current switch and the other through the cut-out magnet and the sustaining coil l to lug *20* on the connection board. The middle point of the starting switch, to which the switch lever is pivoted, is connected through the resistance spools, the cut-out switch, lug *19*, and the tilting magnet to lug *20*. The left-hand contact point of the starting switch is connected to a terminal of the alternating-current switch, and the right-hand point to the negative terminal of the direct-current switch. The plugs y, z on the ends of the alternating-current leads differ in size, and the holes in the plugboard of the autotransformer are of sizes corresponding to the plugs, so that it is not possible to insert the plugs into holes in which they are not intended to go. The autotransformer should be set with the plugboard vertical, so as not to catch dust in the holes.

23. Voltage Transformation.—The eight holes in the plugboard, Fig. 14, are lettered a, b, c, d, e, f, g, h, corresponding to the similarly lettered taps in Fig. 10. Table I gives the plug positions necessary to secure various voltage transformations. Under each alternating-current voltage—200, 220, or 240—the two direct-current voltages given in the first column are the extremes that may be obtained, with the plugs in the given positions, by means of the hand regulating wheel shown at x, Fig. 12. The table will serve as a guide in choosing the plug combinations for different voltages.

The order in which the changes are made to raise or lower the direct-current voltage with any alternating-current voltage is the same; for example, the highest direct-current voltage with any alternating-current voltage is obtained with the plugs in holes b, f and the lowest with the plugs in holes a, h. If it is desired to raise or lower the secondary voltage by changing the plugs, the necessary change can easily be made by following the sequence given in

Table I. A plug position should be chosen so that the exact voltage desired is obtained with the regulator plunger as far out as possible, thus allowing the best circulation of

TABLE I

PLUG POSITIONS FOR VOLTAGE TRANSFORMATIONS

Alternating Current Volts 200		Alternating Current Volts 220		Alternating Current Volts 240	
Direct Current Volts	Plugs In	Direct Current Volts	Plugs In	Direct Current Volts	Plugs In
80–130	*b, f*	95–140	*b, f*	105–140	*c, g*
75–120	*c, g*	90–130	*c, g*	100–130	*b, g*
70–110	*b, g*	85–120	*b, g*	90–120	*b, h*
65–100	*b, h*	85–95	*c, h*	85–110	*a, f*
60–90	*a, f*	80–110	*b, h*	75–105	*a, g*
55–85	*a, g*	75–85	*a, e*	70–90	*a, h*
50–70	*a, h*	70–100	*a, f*		
		65–95	*a, g*		
		60–80	*a, h*		

air in the interior of the regulator. The plugs should never be changed while the current is on.

24. Starting on Live Load.—When starting the converter on a live load, it will not continue to run unless the direct-current voltage of the converter is great enough to force more than about 5 amperes through the storage battery. If the converter starts and then goes out in a few seconds, the regulator handle should be turned to the right, to raise the voltage until the arc continues. The converter will run on a lower current when hot than when cold, and in order to run on a low current it is best to start on a higher one and then by turning the regulator handle to the left, when the apparatus is warm, reduce to the desired current. If when charging a storage battery the starting switch is left in the central position, the converter will automatically cut out

without injury when the battery voltage rises enough to reduce the charging current to about 5 amperes.

25. Starting on Dead Load.—If the converter is to be started on a load consisting of incandescent lamps or other resistance, which is termed a *dead load*, the alternating-current and the direct-current switches are closed, and the starting switch is moved to the left-hand contact, shown at j', Fig. 10. An alternating current then flows through the resistance–the cut-out switch–the tilting magnet–the sustaining coil–the cut-out magnet–the ammeter–and the load, to the autotransformer. This current tilts the bulb, allowing a current to flow across the electrodes s', s, and when the bulb rights itself the arc starts. The converter may also be started by hand, by tilting the bulb through a slot in the top of the cage. When running on a dead load, the starting switch may be allowed to remain on the left-hand contact, and, if the converter stops, due to the failure of the alternating current from any cause, it will automatically start again when the current returns.

26. General Instructions for Operating.—The following general instructions and precautions should be observed:

1. Before attempting to start the converter, see that the apparatus is properly set up in a dry place where exposed iron parts will not rust, and that all connections are correctly made and tight.

2. If starting on a live load, see that the voltmeter reads in the right direction and select a plug position that will give about the required voltage. The positive terminal of the battery should be connected to the side of the switch marked +. See that the starting switch is in the right position; set the regulator with the plunger almost all in, that is, turn the handle to the left almost as far as it will go; and close the alternating-current and direct-current switches. The converter should then start, but if on a live load, it may be necessary to increase the current a little, as already explained, in order to make the operation continuous. After

the converter is running, the desired current can be obtained by turning the regulator handle to the right for an increase and to the left for a decrease.

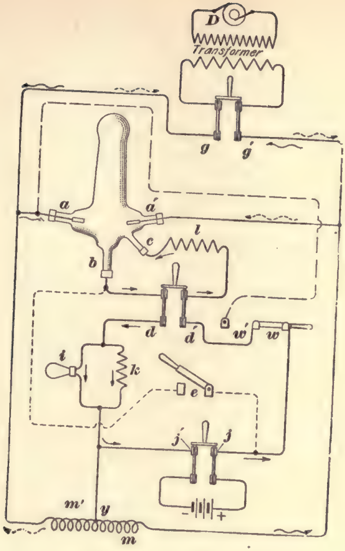
3. To stop the converter, put the starting switch in the off-position and open both the alternating-current and the direct-current switches, either one first, but the direct-current switch should not be left on after the other one is opened.

4. Do not attempt to overload the converter, even for a few moments, or the apparatus may be injured. The maximum capacity is plainly indicated on the name plate and in the manufacturer's instructions.

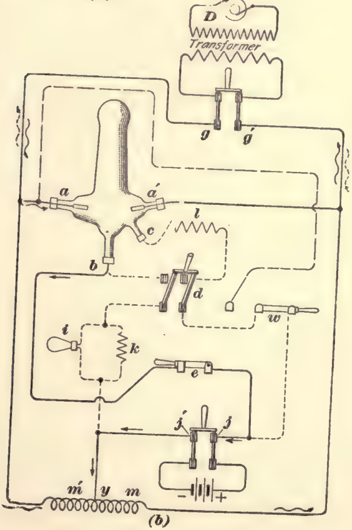
5. Owing to the action of the autotransformer, the alternating-current voltage between lugs *5* and *7* on the connection board, Fig. 14, with 220 volts supply is about 350, and care should be taken to avoid accidental shocks. These lugs are on the bottom of the board where there is ordinarily little likelihood of accidental contact. There are no live contacts on the face of the board, except at the switches, and the voltage there is seldom over 250.

GENERAL ELECTRIC MERCURY-ARC RECTIFIER

27. Simplified Diagram of Connections.—A simplified diagram of connections of the **mercury-arc rectifier** made by the General Electric Company for 10, 20, and 30 amperes, direct current, is shown in Fig. 15. The connections for starting the rectifier on a storage-battery load are shown at (*a*), in which dotted lines and dash lines represent circuits that are then open and need not now be considered. The alternating-current switch *gg'*, the direct-current switch *jj'*, and the starting switch *dd'* are closed. Switch *w* is also closed in its direct-current position. The rectifier is started by a slight tilting of the tube by hand; this causes mercury in the starting anode *c* to join that in the cathode *b*, thereby allowing current to flow from the battery through *j–w–d'–*starting anode resistance *l*–starting anode *c*–cathode *b–d*–pilot lamp *i* and starting resistance *k* (which are in parallel)–*j'*–back to the battery. The arrows show the direction and


D
Transformer
g
g′
a
a′
l
c
b
d
d′
w′
w
i
k
e
j′
j
m′
y
m

(a)


D
Transformer
g
g′
a
a′
l
c
b
d
w
i
k
e
j′
j
m′
y
m

(b)

Fig. 15

path of this current. The breaking of the mercury stream on the righting of the tube causes an arc to form between *c* and *b*. The current from the transformer then flows alternately through *g–a–b–d*–pilot lamp and resistance *k* in parallel–*y–g′*, as shown by the full wavy arrows, and through *g′–a′–b–d*–pilot lamp and resistance *k* in parallel–*y–g*, as shown by the dotted wavy arrows.

The tube is soon warmed by the current passing through it, and then the so-called load switch *e* is closed. Two paths are now available for the alternating current, which may flow from *a* or *a′* through *b–d–i* and *k* in parallel to *y* and also through *b–e–j*–battery–*j′–y*. When the rectifier is operating properly, the switch *d* is opened, thereby giving the circuit shown by the full lines in Fig. 15 (*b*), the circuits indicated by dotted lines being now open at the switch *d*. The pilot lamp *i* is now dark. The starting resistance *k* prevents the current from rising to an excessive strength, and the drop across this resistance allows the pilot lamp to light until the starting switch *d* is opened.

28. The alternator *D* supplies the rectifier with current through an ordinary static transformer that steps the line, or alternator, voltage, which may be 1,000 or more, down to 220 or 110. When the terminal *g* of the supply transformer is positive, the anode *a* is positive and current flows through *g–a–b–e–j*–battery–*j′–y–m–g′*, as shown by the full wavy arrows. As the potential of *a* falls below a value sufficient to maintain the arc, the inductive resistance *m*—whose inductance has been heretofore opposing the increasing current and storing up energy in its magnetic field—produces a current that discharges through *a′–b–e–j*–battery–*j′–y*, and thus maintains the arc. At the same time the supply alternating electromotive force passes through zero, reverses, and builds up sufficiently in the opposite direction to maintain the arc between the anode *a′* and the cathode *b* and to cause a current impulse to pass through *g′–a′–b–e–j*–battery–*j′–y–m′–g*, as shown by the dotted wavy arrows. The inductive resistance *m′* is now charging, and a moment later, as this alternating impulse

decreases in potential, discharges through *a–b–e–j*–battery–*j′–y* and maintains the arc until the alternating current again reverses and builds up sufficiently in the opposite direction to maintain the arc from *a* to *b*.

29. When the rectifier is used for operating lamps or some other kind of a dead load and no storage battery is available for starting purposes, the switch *w* is closed in the

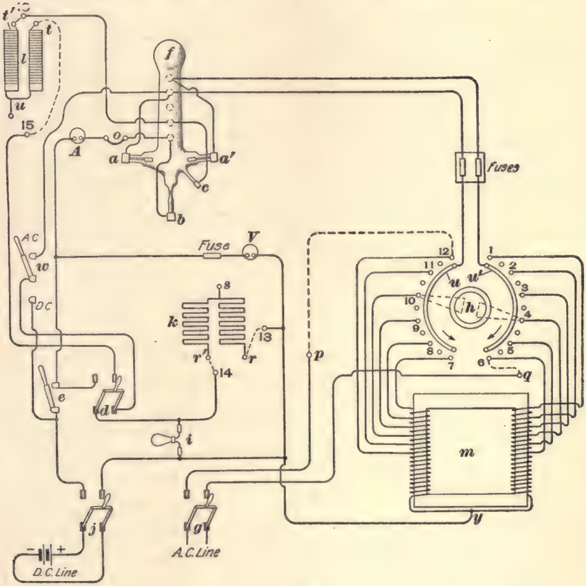


FIG. 16

alternating-current position *w′*, Fig. 15 (*a*), all the other switches being closed, as already described. The load, whatever it may be, will occupy the position shown for the storage battery. The rectifier is started in the same way as before, but in this case the starting current is alternating and flows through *g–w′–d′–l–c–b–d–i* and *k* in parallel–*y–m–g′*.

TABLE II

CONNECTIONS FOR MERCURY-ARC RECTIFIER

Direct-Current Voltage	Connections for			
	Starting Resistance	Starting Anode Resistance	Reactance for	
			220-Volt Alternating Current	110-Volt Alternating Current
80 to 120	*13* to r and *14* to r'	*15* to t and *16* to t'	q to *6* and p to *12*	
46 to 80	*13* to s and *14* to r'	*15* to u and *16* to t'	q to *1* and p to *7*	
30 to 46	*13* to s and *14* to $r\,r'$	*15* to u and *16* to $t\,t'$		q to *6* and p to *12*
16 to 30	*13* to s and *14* to $r\,r'$	*15* to u and *16* to $t\,t'$		q to *1* and p to *7*

When the arc is properly started, load switch e is closed and starting switch d is opened, the same as with a live load.

30. Complete Diagram of Connections.—Fig. 16 is a more complete diagram of connections, showing the apparatus more nearly as actually used; as far as practical the various parts are indicated by the same reference letters as in the preceding figure. In this diagram, o is a circuit-breaker or cut-out; A, the direct-current ammeter; V, the direct-current voltmeter; d, the starting switch; e, the load switch; f, the tube; g, the switch for the alternating-current circuit; h, the dial switch; i, the pilot lamp, which serves as a signal to warn the operator when to open the starting switch; j, the switch for the direct-current circuit; k, the starting resistance,

which is in parallel with the pilot lamp *i*; *l*, the starting anode resistance; *m*, a compensating reactance that is connected directly across the alternating-current supply circuit and divided into several sections with leads running to the dial switch *h*; and *w*, a single-pole double-throw switch on the back of the panel and used only when it is desired to change the connections so that the rectifier can be started on either direct or alternating current.

31. Voltage Transformation.—The connections of the resistances and reactances depend on the direct-current voltage desired and the alternating-current voltage available. The connections are as given in Table II. It will be noticed that for the higher direct-current voltages the two halves of both the starting resistance and the starting-anode resistance are connected in series, and for the lower voltages, only one-half of each is used or the two halves are connected in parallel.

Assuming that forty-four storage-battery cells requiring approximately 2 volts each, or a total of about 88 volts, are to be charged by such a rectifier operating on 220 volts alternating current, the connections will be those given first in the table, namely, *13* to *r*, *14* to *r'*, *15* to *t*, *16* to *t'*, *q* to *6*, and *p* to *12*, as shown by dotted connections in Fig. 16.

32. Starting the Rectifier.—If the rectifier is to be used only for charging storage batteries, the single-pole, double-throw switch *w*, Fig. 16, on the back of the board is closed in the direct-current position *D C* and allowed to remain there; that is, this switch is closed in either position, according to the nature of the work, and is not changed unless the work is to be changed. With the switch *w* closed in the direct-current position, the rectifier is started by closing the circuit-breaker *o*, the starting switch *d*, and the circuit switches *g* and *j*, and by giving the tube a slight shake, thereby causing the mercury in the electrodes *b*, *c* to make contact. Current then flows from the positive terminal of the battery through switches *j*, *w*, and *d*–*15*–starting-anode resistance *l*–*16*–anode *c*–the mercury–cathode *b*–circuit-breaker

o–ammeter *A*–switch *d*–$\left\{\begin{array}{c}\text{pilot lamp } i\\ \mathit{14}\text{–starting resistance } k\text{–}\mathit{13}\end{array}\right\}$–switch *j*–negative terminal of the storage battery. As soon as the tube comes to rest, the mercury stream connecting anode *c* to cathode *b* breaks and the arc starts.

The current through the tube soon warms it, and then the load switch *e* is closed, thereby connecting the positive terminal of the storage battery directly to the cathode *b*. If the rectifier voltage is lower than the battery voltage, the arc will go out at once because the current tends to flow from the battery to the cathode *b* and thence to one of the anodes *a* or *a′*, but the arc will not carry current in that direction. If the arc goes out, switch *g* and then the switch *e* should be opened, the dial switch moved one step counter-clockwise, and the arc started again, as before. This process should be repeated until the arc continues to burn when the load switch is closed. As the dial switch contains five steps and with 220 volts alternating current the whole switch is capable of producing a change of 40 volts direct current (120 to 80), each step causes a change of about 8 volts. If 88 volts is needed, the dial switch must be on the second step from the lowest reading position. This gives about 96 volts across the direct-current circuit—enough in excess of the battery voltage to force a charging current through the battery.

33. As soon as the rectifier is operating properly, the starting switch *d*, Fig. 16, should be opened, thereby cutting out the starting resistance *k* and the pilot lamp *i*, which then goes out, and also opening the circuit containing the starting-anode resistance *l*. The path of the alternating current may be traced as follows: Assuming an instant when point *p* in the alternating-current circuit is positive, and that the dial switch contact arm is in the position indicated by the dotted lines, current flows through *p*–*12*–two sections of the reactance to *10*–contact arm on the dial switch–circular arc *u*–anode *a*–mercury arc to cathode *b*–circuit-breaker *o*–ammeter *A*–load switch *e*–direct-current line switch *j*–the battery–switch *j*–middle, or neutral, point *y* of the compensating reactance

m–one portion of the reactance to the point *6*–*q* to the alternating-current circuit. During the next half cycle, the path of the alternating current is *q*–*6*–two sections of the reactance–*4*–*u'*–*a'*–*b*–*o*–*A*–*e*–*j*–battery–*j*–*y*–*m*–*12*–*p*. The current always flows from one or the other of the two anodes *a*, *a'* to cathode *b* and through the battery from the positive to the negative terminal as a direct current back to the middle point *y* of the reactance.

34. The direct-current voltage, and consequently the strength of the direct current, can be further regulated by turning the dial switch; for example, turning the switch until the arm rests on contacts *3* and *9*, Fig. 16, instead of *4* and *10*, will raise the voltage in the direct-current circuit about one-fifth of the total change possible with any of the connections specified in Table II, and thus increase the current proportionately.

Until thoroughly familiar with the operation of the rectifier, it is best to place the dial switch on the lowest-reading points, that is, on *6* and *12*, when starting. When the required voltage and current are known and the action of the rectifier well understood, the dial switch may be placed on the proper points before trying to start.

When starting the rectifier on a load other than storage batteries, the switch *w* is closed in the alternating-current position *A C*. The process of starting is similar to that already described.

35. Construction of Rectifier.—The General Electric mercury-arc rectifier, as built for commercial use for 10, 20, and 30 amperes output, consists of a *panel*, *tube* (the converter proper), *holder*, and *compensating reactance*. The **panel** for a 30-ampere, 115-volt, single-phase rectifier, with the various devices assembled thereon, is shown in Fig. 17, the reference letters being the same as used in Figs. 15 and 16; it occupies a floor space of 24 in. × 18 in., and when mounted on its frame, the top of the panel stands 76 inches above the floor. On the front of the board are mounted a circuit-breaker *o*, a direct-current ammeter *A*, a direct-current

voltmeter V, a starting switch d, a load switch e, a tube f and its holder, an alternating-current line switch g, a dial switch h for adjusting the reactance coil, a pilot lamp i, and a direct-current switch j.

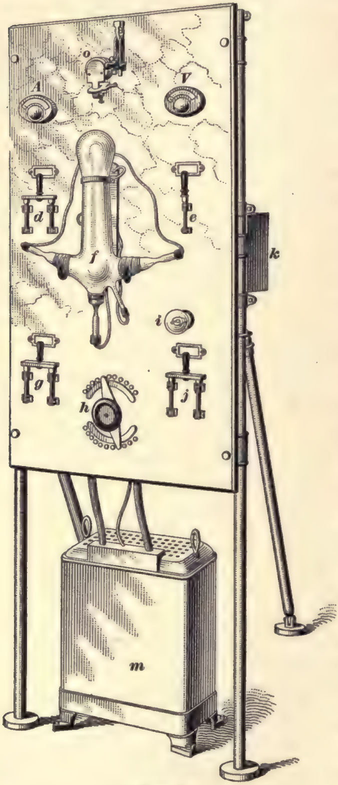


FIG. 17

On the back of the panel is mounted the single-pole, double-throw switch for changing connections, so that the rectifier can be started on either direct or alternating current; also, the starting-anode resistance and fuses for protecting the circuits. The starting resistance is mounted at k on one of the pipe supports for the panel.

The **tube**, which is an exhausted glass vessel, is shown in Fig. 18. It has two anodes, to which connections are made through the metal caps a, a'; a cathode connected to cap b; and a starting anode connected to cap c.

The **tube holder** consists of a supporting frame so arranged that the tube may be tipped sidewise, but it returns to its normal position when released. Terminals, which are connected by flexible wires with the tube electrodes, are mounted on the panel.

The **compensating reactance** may be mounted on the back of the panel or may stand on the floor underneath, as shown at *m*, Fig. 17. Special reactances for smoothing out nearly all the direct-current pulsations are furnished with rectifiers for telephone and telegraph work.

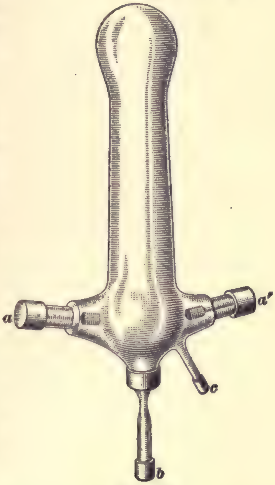


FIG. 18

36. Instructions for Operating Rectifiers.—If the rectifier is used for charging storage batteries, the polarity of the connections must be correct before the apparatus is started, otherwise the tube may be ruined. The panel must be kept in an upright position in order that the mercury may remain in the two lower electrodes. The tube must be handled very carefully, and the seals must not be broken or damaged when installing or connecting. When stopping the charging of a battery, the alternating-current circuit switch should be opened first. On another type of rectifier, the tube is placed on the back of the panel, where it is less liable to injury, and a handle attached to the tube holder for tilting the tube extends through the board to the front.

37. The rectifying devices thus far described are for direct-current outputs not exceeding 30 amperes at not over 120 volts, the alternating voltage being not over 220. Such converters have been developed primarily to meet the demand for simple and easily operated storage-battery charging sets. Tubes for larger direct currents have been built, but they are not very extensively used because the tubes must be so large in order to secure the necessary condensing surface that they are very expensive and difficult to

handle. The larger the current output, the larger must be the tube. Experimental tubes have been built for as high as 100 amperes.

The General Electric rectifiers are designed for a frequency of 60 cycles, but they will operate practically as well on any other frequency from 25 to 140. The Cooper Hewitt converters will also operate satisfactorily over a wide range of frequency.

38. Efficiency of Rectifiers.—The voltage required to force the current through the tubes in commercial use for charging storage batteries is practically 15 volts at all loads; this is the chief source of loss in all mercury converters. The efficiency must therefore depend largely on the voltage used. For example, if the rectifier is delivering 80 volts, a loss of 15 volts in the tube is $18\frac{3}{4}$ per cent., while if it is delivering 120 volts, a loss of 15 volts is only $12\frac{1}{2}$ per cent. There are some additional losses; as a matter of fact, tests on one of the General Electric 30-ampere rectifiers operating on a 220-volt, 60-cycle, alternating-current circuit showed the efficiency to be over 75 per cent. from one-quarter to full load when giving 80 volts in the direct-current circuit, and over 80 per cent. when giving 112 volts in the direct-current circuit. The efficiency is very nearly as high at one-quarter load as at full load.

39. Voltage Regulation.—In the tests just mentioned, the regulation from maximum to minimum current was about 7 per cent., that is, as the current fell from its highest to its lowest value, the voltage rose about 7 per cent. This is a good condition for storage-battery charging because the counter electromotive force of a battery rises as the charging proceeds and thus tends to reduce the current; but as the current decreases, the voltage of the rectifier increases, and thus the two conditions tend to balance each other. The power factor of the rectifier during the efficiency test referred to averaged about 90 per cent.

40. The alternating electromotive force that can be rectified is practically unlimited. Doctor Steinmetz has stated

that it is not probable that any of the high voltages now coming into use for power or lighting purposes will exceed the capacity of a properly designed rectifier with a good vacuum. A small current has been rectified with 36,000 volts alternating electromotive force applied to the rectifier terminals. Numerous tests have been made with from 24,000 to 25,000 volts, giving about 60 kilowatts at 10,000 volts in the direct-current circuit, with a tube slightly larger than can easily be put in a coat pocket. Rectifiers giving from 4 to 6 amperes at several thousand volts are in regular use for supplying direct current for street arc lighting.

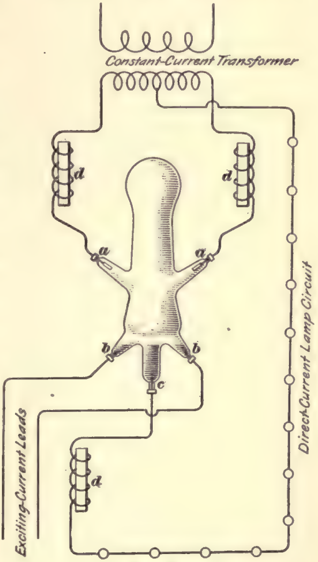


FIG. 19

41. Rectifiers for Street Lighting.—The magnetite mercury-arc rectifier system of street illumination has been put into commercial use in many large cities within recent years and is meeting with much success. The magnetite luminous-arc lamp is described in another Section. At Portland, Oregon, about twelve hundred 4-ampere 80-volt lamps are installed in circuits having about seventy-five lamps each. As the lamps of a circuit are in series, each circuit requires 4 amperes at 6,000 volts (75×80). A mercury-arc rectifier supplies each circuit, receiving its alternating-current supply at 16,000 volts from the secondary winding of a constant-current transformer. The transformer secondary is provided with a center connection for the negative terminal of the lamp circuit.

Each rectifier tube is mounted on a switchboard panel, and provision is made for supplying it with a small amount of 115-volt alternating current for starting, or *exciting*, purposes. The rectifier is started by slightly tilting the tube by hand; after the arc has started, the 115-volt starting current could be switched off, but the practice has been to leave it on.

In Fig. 19 is shown a diagram of the rectifier connections. Each tube has two graphite anodes *a*, *a* for the high-pressure constant-alternating current, two mercury anodes *b*, *b* for the low-pressure exciting current, and a mercury cathode *c*. A reactance coil *d* is placed in each alternating-current lead to the tube and in the direct-current lamp circuit.

42. The tubes used in the Portland system have a drop of about 25 volts, making the loss when carrying 4 amperes about 100 watts. As the tubes have an output of 4 amperes at 6,000 volts, or 24,000 watts, the loss is but $\frac{100}{24000}$, or about .4 of 1 per cent., making the efficiency about 99.6 per cent.

In comparing the mercury-arc rectifier system of supplying direct current for arc lighting with other methods, the losses in all the apparatus necessary to use with the rectifiers should be included. For example, in Portland, the old system included step-down transformers, in which the voltage of the incoming alternating current from the long-distance transmission line was reduced, rotary converters, and motor-generators, consisting of direct-current motors driving direct-current arc machines. The efficiency of the old system from the incoming high-tension alternating current to the direct current supplied to the lighting circuit was about 62 per cent. In the magnetite mercury-arc system now in use, the high-tension current goes directly to the primaries of the constant-current transformers. The losses in these transformers amount to 5 to 10 per cent., according to the size of the transformer. Including the losses in the transformers, the losses in the reactance coils, the exciting-current loss, and the losses in the tubes, the efficiency of the rectifier system is about 88 per cent., that is, 26 per cent. better than the old system. In addition to this gain in efficiency of the

rectifier system over the old system, another feature of importance is that the magnetite lamps, with a consumption of 320 watts each, give even better illumination than the old open-arc lamps formerly in use with a consumption of 500 watts each. The average life of the rectifier tubes in the Portland system is about 650 hours.

VOLTAGE REGULATION

INTRODUCTION

1. With any kind of electric lighting units, steady voltage is necessary in order to obtain steady light. Some kinds of electric lights are much more sensitive to changes of voltage than others. For example, the ordinary carbon-filament incandescent lamp should have a perfectly steady voltage; a varying voltage not only produces very unsteady light, but also shortens the useful life of the lamp. Nernst lamps also require very close voltage regulation. Other electric lights, though not much injured by moderately increased voltage, do not give satisfactory light unless the current supply is at a fairly constant pressure. Electric lamps and their characteristics are fully explained in other Sections.

2. Temperature Changes in Dynamos.—When a dynamo is started after being at rest for some time, all the windings are cool, and their resistances are low. As the machine warms up, the resistances increase, causing greater voltage drop in the armature and series field and reduced current in the shunt field; that is, a weaker shunt field. All these changes tend to make the voltage of the generator gradually decrease as the machine warms up, and, in order to keep the voltage constant, some other change must be made, either by hand or automatically, to compensate for the temperature changes.

3. Drop in Feeder Circuits.—In nearly all electric-light and electric-power systems, the current is carried some

distance from the generators to the lamps, motors, etc. in which it is to be used. Wires called **feeders,** or **feeder circuits,** are used to carry the current from the generators to *centers of distribution*, from which branch circuits lead to the various electrical devices in which the current is to be used. A feeder circuit may consist of one, two, three, or more feeders. For example, feeder circuits for electric-railway systems, in which the current returns from the car motors to the power station through the rails or the ground, consist of one wire only; feeder circuits for electric lamps consist of two or three wires; those for three-phase currents consist of three wires; etc.

If a feeder circuit is carrying no current, there is no drop of pressure in it, and a voltmeter connected anywhere on this circuit will indicate the same pressure as if connected to the generator terminals. However, if current is flowing in the feeders, there will be some pressure drop, and a voltmeter connected to the feeders at a distance from the power station will indicate a pressure less than that of the generators, the difference being practically in direct proportion to the current in the feeders.

4. Effect of Variable Loads.—If adjustments are made at the station so that the voltage at any center of distribution is correct for a given load, a new adjustment must be made every time the load changes; otherwise, the voltage at the center of distribution will change because of the changing drop in the feeders. Load changes may occur gradually and regularly, as, for instance, those due to gradual switching on of lamps near the close of the day, or they may occur suddenly and irregularly, as, for example, those due to the irregular starting and stopping of heavily loaded motors, such as elevator motors.

The gradual variation of load produces such slow changes in the quantity of light given off by lamps that a change is scarcely noticeable until the lamps become very dim or perhaps excessively brilliant. However, it is the slow, imperceptible changes that work the greatest injury to incandescent

lamps and cause the greatest dissatisfaction among persons using them, because readjustments are quite likely to be neglected until mischief is done. Sudden changes, or fluctuations, make the flickering of the lights so noticeable and so objectionable that some remedy is usually applied before much injury is done. In fact, without some means of automatically regulating the voltage, few station managers would use the same feeders to carry current both to incandescent lamps and to motors. It is almost an impossibility for the switchboard attendant to make adjustments that will compensate for changes in line drop caused by a fluctuating motor load; in fact, the attendant is faithful if he keeps the voltage properly adjusted to compensate for the gradual load changes.

5. Life and Candlepower Curves of Incandescent Lamps.—The curves in Fig. 1 show graphically the neces-

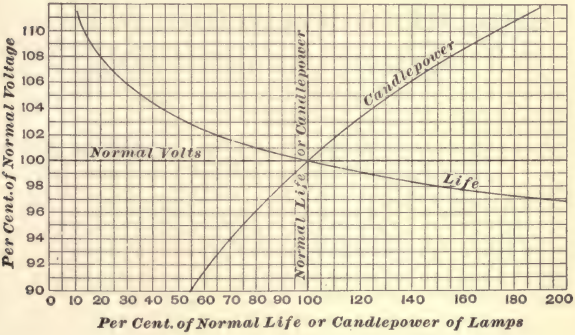


FIG. 1

sity of maintaining absolutely constant voltage on lighting circuits in which carbon-filament incandescent lamps are used. The figures on the left-hand margin are percentages of the normal voltage of the circuit, and those along the lower margin are percentages of both the normal life and the normal candlepower of the lamps. The two curves cross

at the intersection of the 100-per-cent. lines; that is, the life of the lamps will be normal if the voltage is maintained normal. If the voltage is allowed to remain 1 per cent. below normal, or at 99 per cent., the candlepower will be 94 per cent. and the life 123 per cent. of normal; 1 per cent. of increased voltage will result in 6 per cent. of increased candlepower and 20 per cent. of reduced life; etc. When it is remembered that a change of 1 per cent. means a change of only 1.15 volts on a 115-volt system, or 2.3 volts on a 230-volt system, the necessity for close regulation is evident.

6. It is practically impossible to maintain regulation as close as 1 per cent. The best that is usually expected is 2 per cent., and even this cannot be accomplished in large direct-current systems. A variation of 4 or 5 per cent. in the voltage on different parts of such a system at the same time or on the same part of the system at different times is not uncommon. For example, if the normal voltage of the lamps in such a system is 115, one part of the system may be 120 volts while another is 115, or the voltage at any given point on the system may vary between 110 and 115, even though the station voltage is well regulated. The reasons for such variations are as follows:

The voltage at the lamp terminals is the difference between the voltage generated at the station and that lost in the lines leading to the lamps. If all the feeders leading from a direct-current power station are equally loaded, it is possible to make the station voltage high enough to allow for the feeder drop and still leave normal pressure at the lamp terminals; but one feeder may be carrying its maximum current while another is carrying only very little. An attempt to compensate for the drop in the heavily loaded feeders by raising the station voltage results in too much pressure on the lamps that take current from the lightly loaded feeders.

7. Independent Feeder Regulation.—In large, direct-current, constant-potential systems, independent feeder regulation is sometimes accomplished by means of storage batteries connected directly across the feeder circuit, that

is, *floating* on the circuit. When the feeder voltage tends to rise above normal, current flows into the batteries and charges them; when the feeder voltage tends to fall below normal, the batteries discharge into the circuit. This keeps the feeder current, and hence the feeder drop, nearly constant. In one instance, a circuit, on which the voltage before the installation of a storage battery reached a minimum of 96 volts and a maximum of 128 volts during 24 hours, did not show a variation of over 2 volts either way from 112 volts normal during the same length of time after a storage battery was installed.

In most direct-current lighting stations, however, no attempt is made to regulate the voltage on individual feeders. The best that can be done in such cases is to arrange the lamps so that the various feeders will be loaded as nearly alike as possible, and then keep the station voltage enough higher than the lamp voltage to make up for the line drop. This method, it is true, causes the lamps near the station to operate on a higher voltage than those at a distance. To compensate for this difference, it is the practice in some large, direct-current systems to install higher voltage lamps near the stations than at a distance. For example, the lamps near the stations may be made for 115 volts, while those at the ends of the lines may be for 110 volts.

8. Pressure Wires.—In order that the station attendants may readily know the voltage near the lamps, pressure wires are sometimes connected to the circuits at the important centers of distribution and led back to the station voltmeter. As these wires carry only the very small current taken by the voltmeter, the exact voltage at the center to which the instrument is connected is indicated by the voltmeter.

9. Methods of Voltage Regulation.—The voltage of a dynamo may be regulated by changing its speed or its field strength. The machine supplying the motive power is usually provided with a speed governor in the attempt to maintain constant speed, and occasionally an attempt is made

to compensate for changes of voltage due to changing loads by means of an electrically operated governor. For example, the governor on some engines or waterwheels may be adjusted so that the speed at full load will be slightly higher than that at no load.

This method of voltage regulation may sometimes be made to work satisfactorily if the load changes occur slowly; but the inertia of the moving parts of the engine and dynamo is far too great to permit speed changes quick enough to keep the voltage steady when the load is changing suddenly. As a matter of fact, engine and waterwheel governors very frequently fail to maintain even a constant speed under changing loads; a suddenly increased load, for instance, may cause a drop in speed great enough to make a perceptible change in the brilliancy of the lamps, though in a moment the governor may act to readjust the speed.

10. Nearly all dynamos used for lighting purposes are overcompounded enough to make up for the drop in the line, provided the speed of the dynamo remains constant; in fact, some dynamos are overcompounded enough to compensate not only for the drop in the lines, but also for some drop in speed. If a direct-current dynamo is properly overcompounded and its speed is kept constant, there is little else that can be done to maintain constant voltage, except to adjust the field strength to compensate for increased shunt-field resistance as the field temperature rises. However, many dynamos are not properly overcompounded and many engine governors do not work theoretically perfect; to compensate for such imperfections, automatic voltage regulators are used.

REGULATORS FOR DIRECT-CURRENT CIRCUITS

CHAPMAN REGULATORS

11. W. H. C. Type Regulator.—Voltage regulators for direct-current circuits operate by automatically varying the field excitation of the dynamos that feed the circuits. In the **Chapman voltage regulator,** electromagnets move a contact shoe over a series of segments to which the sections of a resistance are connected, and thus cut resistance in or out of the shunt-field circuit of the dynamo with which the regulator is used.

Fig. 2 shows the front of a Chapman **W. H. C. type voltage regulator,** for use with either direct- or alternating-current dynamos. The three essential parts are: (1) A *relay*, or contact maker, *a*, for detecting variations of voltage and applying the corrective force; (2) a *rheostat* mounted behind the board, its sections terminating in a set of copper segments *c*; and (3) a pair of *working solenoids* *b*, *b*, to operate the rheostat in response to the action of the relay.

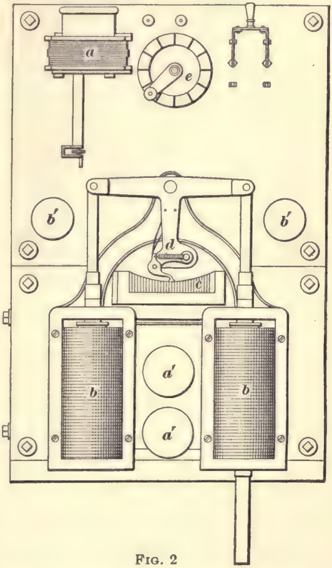


FIG. 2

12. Fig. 3 (*a*) and (*b*) shows the construction of the **relay.** In (*b*), the magnet coil *a* is shown in cross-section; it may have a single winding connected directly across the circuit in which the voltage is being controlled, or it may be compound-wound, one of the two windings being connected across the circuit and the other in series with the circuit. The series winding is used to compensate for line drop, so as to keep the pressure constant at some distant point on the line. If pressure wires are brought back from the distant point to the terminals of the relay magnet, only a shunt winding is necessary; but if not, a series winding is arranged to act differentially with the shunt winding. For example, if a large current is flowing, the pressure at the distant point will be less than that at the station by the amount of drop in the circuit to the point. The series winding weakens the magnet just in proportion to the increased flow of current, or increased drop.

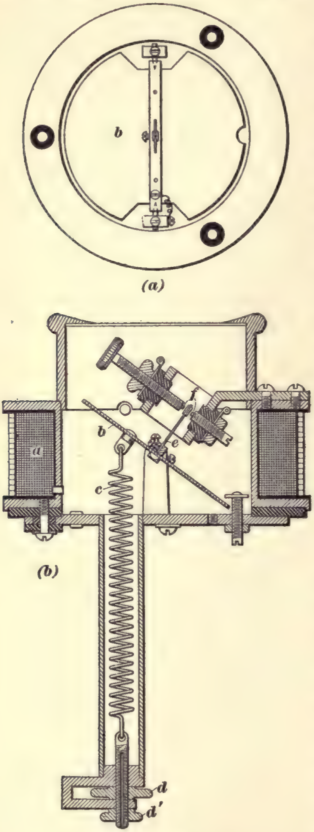


Fig. 3

An iron disk *b* is pivoted inside the coil, so that the tendency of the magnetism is to move the disk to a vertical

position. Fig. 3 (*a*) is a plan view, showing the method of pivoting the disk. The pull of the magnet is opposed by a coiled spring *c*, Fig. 3 (*b*), the tension of which may be adjusted by means of a nut *d* held at the desired setting by a clamping nut *d'*. Attached to the center of the disk is a spring *e*, the platinum tip of which can be brought against either of two platinum points *f*, according as the pull of the magnet or that of the spring becomes the stronger. Suitable stops are provided, so as to prevent excessive movements of the disk in either direction.

13. The **rheostat** for the smaller sizes of regulators consists of units made of resistance wire covered with enamel; for the larger sizes, the units are made of cast-iron grids. The copper segments to which the units are connected are arranged in the arc of a circle on the face of the regulator, and contact shoes pivoted to a lever arm are swept over the surface of the segments by the movements of the arm. The shoes are held in contact with the segments by coiled springs *d*, Fig. 2. This rheostat is additional to the ordinary hand-operated field rheostat.

14. Fig. 4 shows a general diagram of connections of a W. H. C. voltage regulator for a direct-current circuit. The relay magnet *a* shown in section, has a compound winding. The shunt winding is connected directly across the circuit to be controlled, and has one or two ordinary carbon-filament incandescent lamps *a'* in its circuit. The resistance of the wire in the relay coil increases as it gets warm in service, but the resistance of the lamp filaments decreases, and the resultant of the wire and the lamps in series is very nearly a constant resistance. The series winding, being connected across the terminals of the shunt block, carries a current proportional to the total current in the line, and has numerous taps brought out to a compound switch, by means of which the number of effective turns may be adjusted so as to get any desired compounding effect. The compound switch *e* is designated by the same reference letter in Fig. 2.

15. The working solenoids, or operating magnets, *b*, Fig. 4, have two windings—a primary winding, which is fed with live current when the circuit through it is closed by the relay, and short-circuited secondary winding, in which a current is induced when the relay opens the circuit through the primary. The induced secondary current helps to kill the inductive discharge, which would otherwise cause bad sparking at the relay contacts. Incandescent lamps *b′* connected in

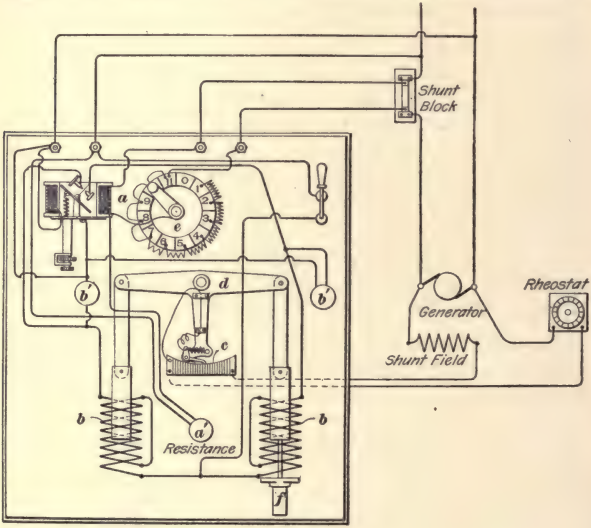


FIG. 4

shunt with the relay absorb what little inductive kick remains, so that the contacts are practically sparkless. Lamps *a′*, *a′* and *b′*, *b′* are on the front of the regulator, as shown in Fig. 2.

The rheostat contact segments are shown at *c*, Fig. 4. The arm carrying the contact shoes is part of a beam *d*, to the ends of which are attached, by links, the cores of the operating magnets. When relay spring *e*, Fig. 4, touches the upper contact, the left operating magnet is active; when *e*

touches the lower contact, the right operating magnet is active, and the beam moves accordingly. To the lower end of one of the magnet cores is attached a dashpot *f*, which prevents too sudden movements of the beam.

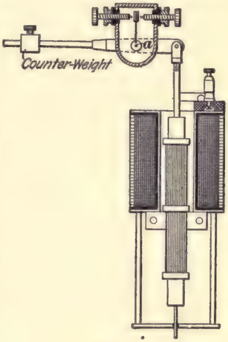


FIG. 5

16. Belknap Type Regulator. In the **Belknap type regulator,** the relay operates by tilting a lever to which a contact spring is attached. Fig. 5 shows a section of the relay; the contact lever is pivoted at *a*. The working solenoid, a section of which is shown in Fig. 6, consists of two differentially wound coils *a* and *b* mounted on a brass tube. Inside the tube is a movable iron core *c*, which has an adjustable passage through its center. The ends of the tube are closed, and the spaces at the ends of the core are filled with oil. The core can move endwise only as fast as the oil can flow through the passage in the core. A vertical post *d* attached to the core carries the arm *e* to which the contact shoe *f* is attached. As the core is moved back and forth in the tube, the shoe rubs over the

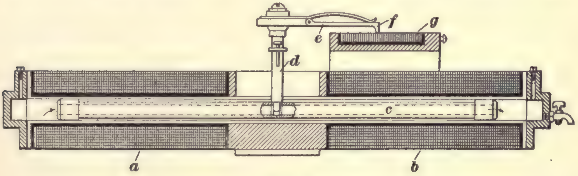


FIG. 6

set of resistance contacts *g* to which the sections of the rheostat are connected.

Fig. 7 shows a section of the regulating valve by which the oil passage in the core is adjusted. The vertical post *d* is the same as post *d*, Fig. 6. A plunger *a*, Fig. 7, in the post is raised or lowered against a coiled spring *c* by means

of a thumb nut *b*. This arrangement permits the size of the oil passage to be increased or decreased, and allows the rate of motion of the core in the tube to be varied.

Each of the two coils composing the working solenoid is made up of three sections of wire: an inside, an outside, and a middle section. The inside and the outside sections are connected as one, and the number of turns of wire in the two together is exactly equal to the number of turns of wire in the middle section. Under normal conditions, with the relay balanced, there is a current flowing through only the middle section of each coil. This magnetizes the core strongly and pulls it equally in opposite directions, so that it remains indifferently in any position where it happens to be.

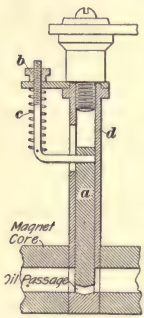


FIG. 7

17. Fig. 8 shows a diagram of connections of a Belknap regulator on a direct-current circuit, the regulator relay magnet in this case being compound-wound. When the switch *a* in the line leading to the working solenoid is closed, current can pass from the positive side of the circuit through the switch *a*, the middle winding *3–4* of the left-hand coil, the middle winding *4′–3′* of the right-hand coil and back to the negative side of the circuit. This current flows clockwise (facing the right end of the solenoid) in one winding and counter-clockwise in the other, so that there is no tendency to pull the core in either direction.

If the voltage of the circuit at a distant center of distribution becomes low, the core of the relay magnet settles, bringing the relay-contact tongue against the right contact. The current from the positive side of the circuit then divides at *b*, one part flows clockwise through the middle winding *3–4* of the working solenoid, and the other counter-clockwise through the inside and outside windings *2–1* and *6–5* and through the relay contact back to the point *0*, where the two currents unite; both currents than flow counter-clockwise

through the middle winding $4'-3'$ of the right end of the solenoid, and back to the negative side of the line. As the three windings on the left end of the solenoid neutralize one another, there remains only the pull due to the middle winding on the right end, and the core moves to the right, causing the shoe f to slide over the contacts g and to cut out resistance from the shunt-field circuit. The resistance used is additional to that of the regular field rheostat. The neutralizing effect of the windings on the solenoid results in

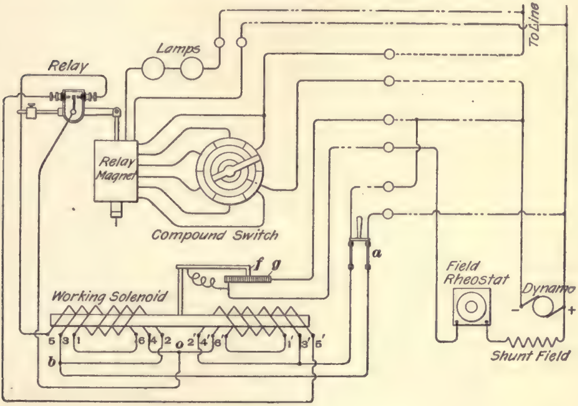


FIG. 8

no sudden dying out of magnetism when the relay contact breaks; hence, no inductive sparking occurs at the contacts.

When the line voltage is too high, the relay contact closes to the left, the magnetizing effects of the windings on the right end of the solenoid neutralize each other, and the core moves the contact shoe to the left, thus cutting resistance into the shunt-field circuit. Either type of Chapman regulator just described will regulate the voltage at the point on the circuit for which it is adjusted within 1 per cent. For special purposes, either regulator can be constructed for regulation even closer than 1 per cent.

TIRRILL REGULATORS

18. T D Type Regulator.—Fig. 9 (*a*) shows the front of a **Tirrill regulator** for direct-current circuits, designated as the **T D type.** Fig. 9 (*b*) shows a diagram of the simpli-

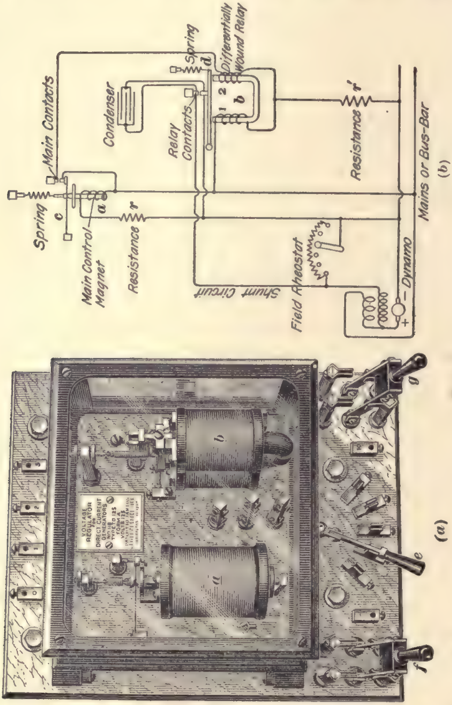


FIG. 9

fied connections to a compound-wound dynamo. The main control magnet *a* takes current from the bus-bars or from the pressure wires brought back from a distant center of distribution. The relay magnet *b* is differentially wound,

the two windings being so connected that when current flows through both coils, the magnetizing forces of these coils oppose each other, thus making the magnetism in the core the resultant of the two forces. The magnetism when both coils are active is thus weaker than the magnetism when only one coil is energized.

Above the main control magnet *a* is pivoted a lever *c*, and above the relay magnet *b*, a lever *d*. Each lever is subjected to the opposing pulls of its magnet and an adjustable coiled spring, which holds the contacts closed when the magnets are not excited. For best results, enough of the generator field rheostat should be cut into circuit to lower the voltage about 40 per cent. below normal. Magnet *a* then being weak, the main contacts close, winding *2* of relay magnet *b* is energized (winding *1* already being energized), and the magnet is thereby so weakened that the relay contacts close and short-circuit the field rheostat. This subjects the shunt field to the full voltage of the generator and causes a large field current to flow. The generator voltage therefore builds up rapidly until magnet *a* becomes strong enough to open the main contacts, thus cutting off the current from one winding of the relay magnet and causing the relay contacts to open. This puts the field rheostat in circuit again, and the shunt-field current drops to the original amount, causing the voltage to fall until the main contacts again close. These actions are continually repeated while the machine is in operation, the contacts opening and closing at frequent intervals. The self-induction of the shunt field would cause considerable sparking at the relay contacts when they open, were it not for the condenser connected across them; this absorbs the discharge current and prevents sparking. The resistances r, r' limit the current through the magnets.

19. Fig. 10 shows the connections of a T D regulator to two direct-current, compound-wound generators *A B* arranged for parallel running. The regulator can be used to regulate any one of five generators in parallel; it is connected to the

desired machine by means of the five-point rotary switch *e*, shown closed in position for regulating generator *B*. In the lower corners of the panel are two double-pole, double-throw switches, which serve to reverse the direction of the flow of current through the contacts. On the back of the panel is mounted the resistances and the condenser shown diagrammatically above and below the panel. The main control-

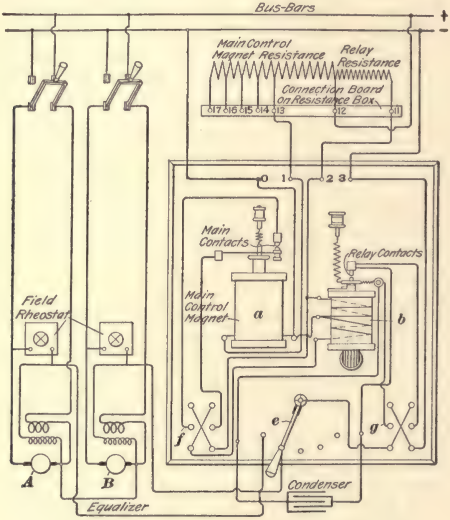


FIG. 10

magnet resistance has a number of taps, by means of which the voltage maintained by the regulator may be changed. For example, a 125-volt generator may be used to supply circuits with 105, 110, 115, 120, or 125 volts by connecting binding post *1* at the top of the panel with posts *13*, *14*, *15*, *16*, or *17* on the resistance box.

20. When the regulator is applied to any one of several compound-wound generators operating in parallel, this

generator will tend to take all the sudden fluctuations of load, but the load will become very quickly equalized among the several generators due to the series winding and the equalizer connections. Shunt-wound generators adjusted for parallel operation will share the load properly so long as none of the shunt fields are readjusted; but if any field is changed by cutting resistance in or out, all the other fields must be correspondingly changed, or the load will no longer be properly shared by the dynamos. If automatic regulators are used

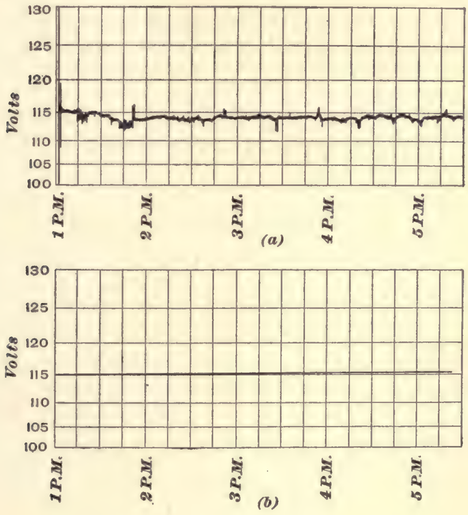


FIG. 11

with shunt-wound generators in parallel, it becomes necessary to use a regulator with each machine.

21. In Fig. 11 (*a*) is shown a chart taken by means of a recording voltmeter from a system where no automatic voltage regulator was in use, but where the regulation was very good, probably better than the average where motor

service is supplied. In (*b*) is shown a chart taken from the same system after the installation of a Tirrill regulator. In chart (*a*), the voltage varies from about 116 volts maximum to about 112 volts minimum; that is, from nearly 1 per cent. above normal to $2\frac{1}{2}$ per cent. below normal. From the candlepower curve in Fig. 1 this variation corresponds to a variation of candlepower from 105 to about $87\frac{1}{2}$ per cent. of normal, or a total change of $17\frac{1}{2}$ per cent. As this change occurred quite suddenly in some instances, the changing brilliancy of the incandescent lamps must have been quite noticeable. In chart (*b*), the voltage shows no sudden variations whatever, but rises gradually as the load increases toward evening.

REGULATORS FOR ALTERNATING-CURRENT CIRCUITS

ALTERNATOR REGULATORS

22. Voltage regulators for alternating-current circuits may be considered in two divisions: (1) Regulators arranged to change the voltage of the alternators, which may be called *alternator regulators*, and (2) regulators for operating directly on the feeders, called *feeder regulators*. Either type of Chapman regulator already described can be employed to control the voltage of alternators by using an alternating-current relay magnet.

23. T A Type Regulator.—Fig. 12 shows a diagram of the connections of a Tirrill regulator for alternating-current circuits, known as the **T A type.** Direct-current magnets *a*, *b*, levers *c*, *d*, the relay contacts, the condenser, and the connections of the exciter generator with its field rheostat, etc., are practically the same as in the T D regulator, Fig. 9 (*b*). The direct-current, control-magnet lever *c* in the T A regulator, Fig. 12, is pivoted near its center. The movements of the lever are caused by differences between the downward pull of the magnet core and the upward pull

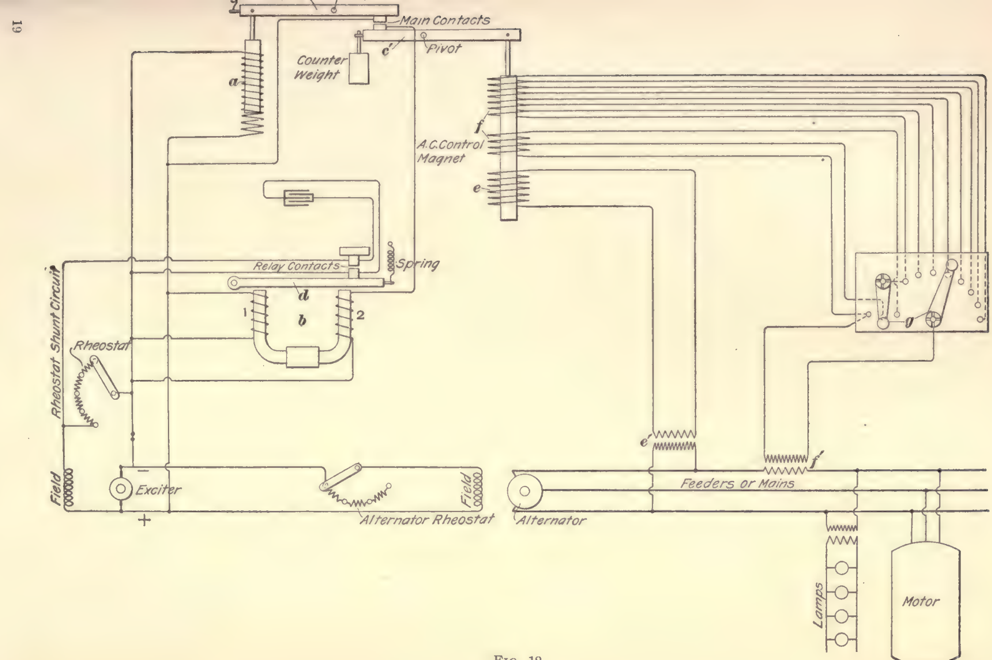

Main Contacts
Pivot
c'
Counter Weight
a
f
A.C.Control Magnet
e
Relay Contacts
Spring
d
1
b
2
Rheostat
Rheostat Shunt Circuit
Field
Exciter
−
+
Alternator Rheostat
Field
Alternator
e'
f'
g
Feeders or Mains
Lamps
Motor

Fig. 12

of a coiled spring, both attached to the same end of the lever. The other end of the lever carries one of the main platinum contact points. The other main contact point, also made of platinum, is carried on one end of a third lever c'. This lever also is pivoted near its center; it carries a counterweight suspended from the end on which the main contact is placed, and the core of the alternating-current control magnet is suspended from the other end. The magnet core, the counterweight, and the location of the pivot are so chosen that, without the pull of the magnet, the core will fall and close the main contacts.

The alternating-current control magnet has two windings: a potential, or shunt, winding e, that, when current flows in it, tends to raise the core, and a compensating, or series, winding f, the magnetizing force of which opposes that of the shunt winding. The shunt winding receives its current from the secondary of a potential transformer, and the series winding is supplied by the secondary of a current transformer. Both transformer primaries are connected to the circuit to be regulated. The compensating winding is in two sections, each provided with a number of taps that are connected to points on regulating switches, so that the effect of the winding can be adjusted to make the combined effect of the shunt and the series windings proportional to the drop to any point on the line. For example, if the current increases, thus causing an increased drop in the feeders, the control magnet is correspondingly weakened by the increased current in the compensating coil, and the core falls enough to close the main contacts.

24. When the alternating-current control magnet weakens, its core drops, with the result that the main contacts are closed, thus closing a circuit through winding *2* of relay magnet b. As windings *1* and *2* are so connected that their effects are opposed to each other, the relay magnet is weakened when winding *2* is energized, and lever d is drawn up by a coiled spring until the relay contacts close, thus short-circuiting the exciter field rheostat. The exciter voltage then

rapidly builds up until magnet *a* causes the main contacts to open. The increased exciter voltage causes increased current in the field of the alternator, thus increasing the alternator voltage.

When a high voltage is required from the alternator, the core of the direct-current control magnet *a* will be drawn down and held lower than when a low voltage is required; that is, the main contacts are held higher, and the core of the alternating-current control magnet must settle lower to close the main contacts. As the position of the main contacts varies according to the voltage of the alternator, they are frequently called **floating contacts.**

FEEDER REGULATORS

25. Voltage regulators can be used very successfully with alternating current because of the ease with which alternating-current pressures can be raised or lowered by transformer action. With alternating current, a transformer can be so connected in each feeder circuit that the pressure of the circuit can be raised or lowered as desired, independently of any other pair of feeders.

Feeder regulators may be considered in two classes: *switch-type regulators* and *induction-type regulators.* Either of these may be hand-operated or automatically operated. In a switch-type regulator, the voltage is varied by changing the number of effective turns on the secondary of a transformer, and in the induction-type regulator, by changing either the relative quantity or the direction of the magnetic flux enclosed by the primary and secondary coils.

SWITCH-TYPE REGULATORS

26. Hand-Operated Regulators.—In Fig. 13 is shown a diagram of the circuits of a General Electric **C R type compensating transformer,** or **compensator.** The winding is in two parts, both of which are connected to the line *x*; therefore, the device is an autotransformer, though

the name compensator is more commonly used. The part of the winding connected directly across the feeder circuit is the primary; the other part, or the secondary, when in circuit, is in series with the feeder.

27. To understand the action of the C R type compensator, consider an instant when line *x*, Fig. 13, is positive and line *y* negative. If the reversing switch *a* is closed to contact *11*, current will flow through the transformer, as indicated by the full-line wavy arrows; the current through the primary coil will cause an electromotive force to be generated in the secondary coil in the direction indicated by the dotted arrow. The electromotive force of the secondary coil is in the direction of the flow of current; that is, with switch *a* closed as indicated by the arrow, the compensator raises, or boosts, the voltage of the line. When the dial switch is on contact *1*, the maximum boosting effect is obtained, for the whole secondary coil is in circuit. As the dial switch is turned clockwise, the secondary coil is gradually cut out of circuit, and when contact *11* is reached, there is no boosting effect whatever, for all of the secondary coil is cut out of circuit.

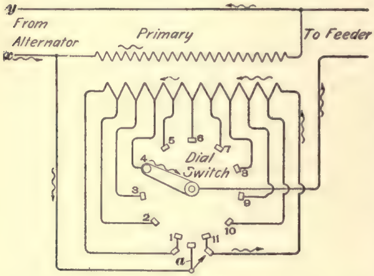


Fig. 13

Further clockwise movement of the dial switch automatically throws the reversing switch from contact *11* to contact *1*; and as the dial switch moves to contacts *2*, *3*, *4*, etc., the secondary coil is again gradually cut into circuit, this time with the current flowing through it in the opposite direction to that during the first revolution of the switch. As the electromotive force of the secondary coil is in the same direction as before, the feeder voltage is lowered by an

amount corresponding to the position of the dial switch. The maximum lowering effect is obtained with the reversing switch *a* on contact *1* and the dial switch on contact *11*. To reverse the action, the dial switch is rotated counterclockwise, the first revolution gradually increasing the feeder voltage to that of the alternator, and the second revolution gradually boosting it to its maximum value; in this case, the reversing switch is thrown from contact *1* to contact *11* when the dial switch passes from *1* to *11*.

The dial-switch blade is made too narrow to bridge the gap between segments, so that there is no short-circuiting of sections of the secondary coil. The movements of the blade are effected through a compression spring. The blade is retarded by a catch until the movement of the operating handle has compressed the spring sufficiently to carry the blade from contact to contact with such a quick snap that, although the circuit through the secondary is momentarily broken, no flicker can be observed in lamps supplied through the feeder.

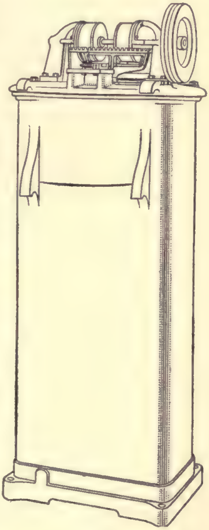


Fig. 14

28. Automatically Operated Regulators.—In the General Electric **B R type regulator,** the steps of the secondary coil of a compensator are automatically cut in or out in either direction required to keep the voltage constant. Fig. 14 shows the complete regulator. The coils are immersed in oil in the bottom of the case, and the controlling mechanism is attached to the cover, which is shown removed from the case in Fig. 15 (*a*). The horizontal shaft *a*, Fig. 15 (*a*), carrying two loose bevel pinions is kept rotating by means of a pulley *b* belted to some convenient source of power. Both pinions mesh with a bevel

gear *c*, which is keyed to a vertical shaft that carries the regulator arm underneath the cover. An electromagnet is arranged near each loose pinion, so that when the magnet is excited, its armature grips, or clutches, the pinion and

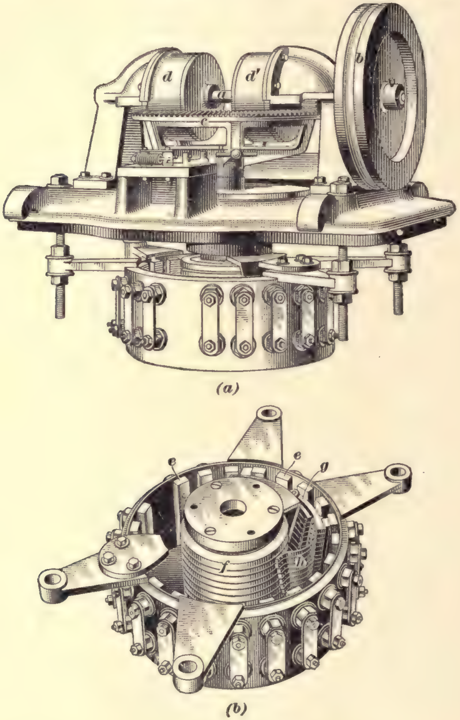


Fig. 15

causes it to rotate with the shaft. These magnetic clutches and pinions are contained within the casings *d*, *d'*.

The dial switch for changing the connections to the transformer secondary consists of three separate parts: (1) a set

of stationary vertical bars *e*, Fig. 15 (*b*), placed on the inside of a cylindrical cast-iron ring, or pot; (2) a set of stationary collector rings on a cylinder *f* inside the cast-iron pot and concentric with it; and (3) the moving part, which carries the contact fingers and brushes *g*. The fingers *g* are attached to the arm carried by the vertical shaft, which extends through the center of cylinder *f*. When the shaft is rotated by the beveled pinions and gear above the cover, the fingers slide over the bars *e*. To each finger is attached a metal strip, or brush *h*, which bears on a collector ring on the cylinder *f*. Each finger with its brush is insulated from the other fingers and brushes.

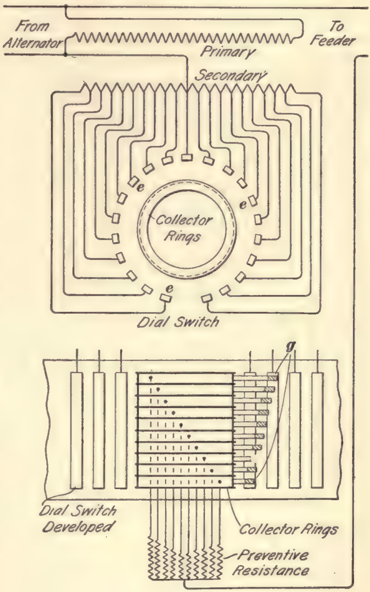


FIG. 16

29. Fig. 16 shows the internal connections of the B R type regulator. The upper portion is an end view, showing the connections of the vertical bars *e* to the secondary coil, but not showing the fingers and brushes; the lower portion is a side view, showing the development of a portion of the cast-iron pot. The fingers are graded in length, so that while the top finger rests on the center of one bar, the bottom finger rests on the center of the next adjacent bar. If single fingers could bridge across the spaces between the

bars, they would short-circuit sections of the secondary coil; hence, the individual fingers are made too short to span the spaces. Each collector ring is connected to the line through a resistance that not only prevents excessive current flow between the bars as the fingers pass over them, but also makes the change of voltage more gradual. As the connection between the bars and brushes is never broken, no sparking can occur. No reversing switch is provided in the

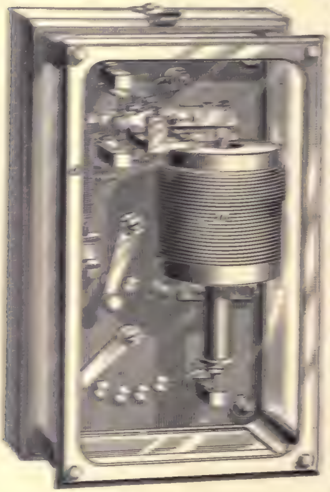


FIG. 17

B R regulator but, instead, the secondary winding is made capable of giving, without reversal, the entire range of voltage control required. The connection from one of the alternating-current mains is made at the center of the secondary coil; thus, the sections on one side of this connection serve to raise the line voltage, and the sections on the other side, to lower the line voltage.

30. Potential Relay.—In Fig. 17 is shown the potential relay, or contact-making voltmeter, used to detect changes in the feeder voltage and control the circuits through the magnetic clutches on top of the regulator. A magnet *a* has a movable core, which is attached to one end of a pivoted lever *b*. The other end of the lever carries platinum contact points *c* that touch corresponding stationary platinum points above or below whenever the lever is tilted from a horizontal position. The core is supported partly by the adjustable spring *d* and partly by the pull of the magnet. When the magnet weakens, the core settles.

The magnet has two windings—a potential winding and a compensating winding—arranged to give a compounding effect that is exactly the same as on the alternating-current control magnet of the Tirrill regulator shown in Fig. 12. The relay, Fig. 17, can be adjusted to close one or the other of the contacts *c* whenever the voltage at a distant center of

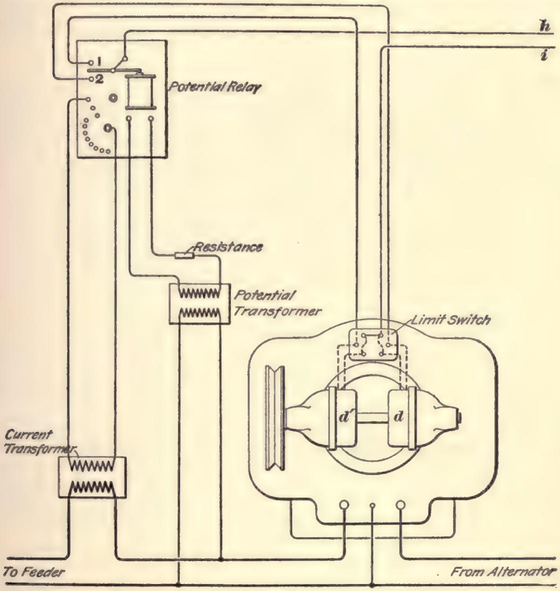


FIG. 18

distribution rises or falls an allowed percentage from normal. The double winding on magnet *a* is unnecessary if pressure wires are brought back from the center of distribution.

31. Fig. 18 shows the external connections of the type B R regulator with a potential relay. When the contact lever on the relay touches contact *1*, the clutch magnet *d'* is energized and the regulator arm is moved in one direction.

When the lever touches contact 2, magnet *d* is energized and the regulator arm is moved in the opposite direction. A limit switch opens the circuit through the magnets when the arm has reached the limit of its travel in either direction. The lines *h*, *i* are connected to any convenient source of direct current.

Fig. 19 shows two records made by a recording voltmeter connected to a feeder circuit on which a B R regulator was

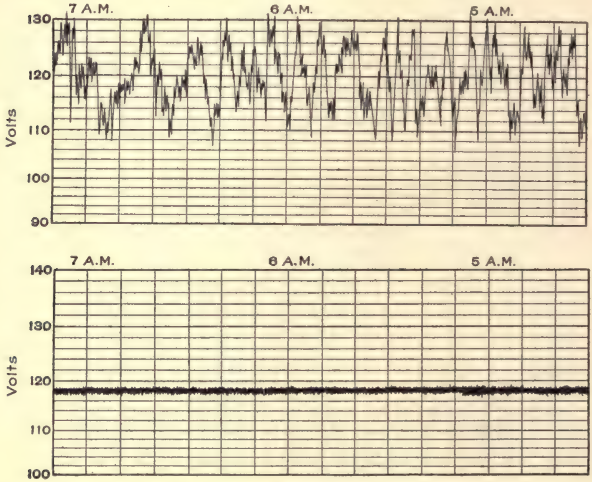


FIG. 19

used. The upper record shows the extremely rapid variations of voltage on the alternator side of the regulator, while the lower one shows the practically constant voltage on the feeder side.

INDUCTION-TYPE REGULATORS

32. Single-Phase Regulators.—A **single-phase induction regulator** is essentially a transformer having a movable primary coil so arranged that any desired portion

of the magnetic flux set up by this coil may be made to pass through the secondary coil. The directions of the magnetic fluxes of the two coils may be made to coincide with or to oppose each other. The simplified connections of a single-phase induction regulator are shown in Fig. 20 (*a*), (*b*), and (*c*). A stationary cylindrical shell, or core, has two

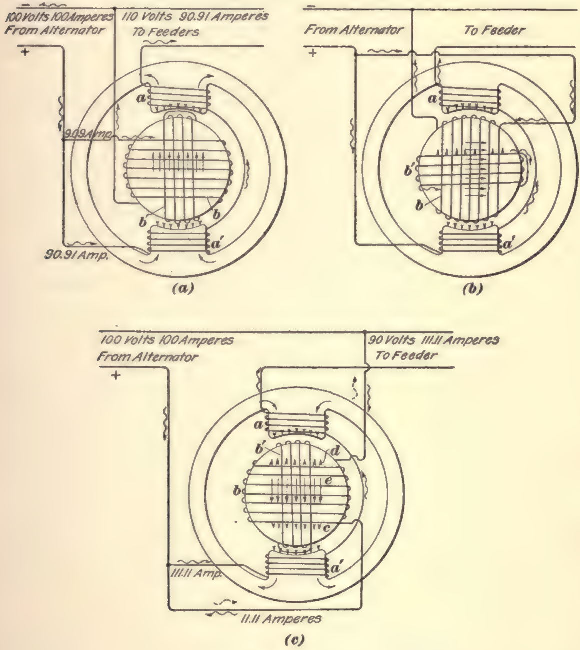


FIG. 20

inwardly projecting poles, on which are placed the two secondary coils a, a' connected in series with the feeder circuit to be controlled. A movable cylindrical core, represented for convenience as spherical, is arranged so that it can be turned through an arc of 180° between the two poles.

On this core are two coils: the primary, or shunt coil *b* connected across the feeder circuit, and a short-circuited coil *b'* at right angles to the primary coil.

The arrows and the arrowheads in the figure show conditions during one alternation; these arrows and arrowheads should be reversed to show the conditions during the next alternation. The direction of flow of the instantaneous alternating current is shown by wavy arrows, the direction of the magnetizing force of the primary winding by straight and curved arrows on the core and shell, respectively, and the direction of the magnetizing force of the secondary winding by the arrowheads on the pole faces.

33. In Fig. 20 (*a*), the magnetizing force of the primary coil sets up a flux through the core, the poles, and the shell in opposition to the direction of the magnetizing force of the secondary coil. This primary flux sets up in the secondary coil an electromotive force that agrees in direction with the flow of the feeder current through the coil, and the feeder voltage is therefore boosted.

In (*b*), the armature has been turned clockwise through 90°, or until the direction of the magnetizing force of the primary coil is at right angles to that of the secondary coil, so that neither coil affects the conditions in the other. In this position of the armature, the secondary winding would set up considerable flux through the core, the poles, and the shell, and would thus introduce a considerable inductance into the feeder circuit were it not for the short-circuited winding *b'* on the core. The current in the short-circuited winding takes the direction indicated by the wavy arrows and prevents the building up of a large secondary flux.

Fig. 20 (*c*) shows the conditions with the core rotated 180° from its first position. With no load in the line, the magnetizing force of the coil *b* at a given instant is in the direction shown by the arrowheads *c*, the magnetizing current being in the direction of the dotted wavy arrows. This flux sets up in the coils *a a'* an electromotive force opposing that of the line; that is, the line voltage is lowered. If a line current is

flowing at the given instant, it sets up a magnetic flux, as shown by the arrowheads on the pole faces. This flux, being in the same direction as the no-load flux set up by the coil *b*, causes the counter electromotive force in coil *b* to exceed the impressed electromotive force, and the current in this coil is reversed, as shown by the full-line wavy arrows along the conductors leading to the coil; also, when a line current of sufficient size is flowing in coils *a*, *a'*, the current in coil *b* will tend to set up a flux in the direction of the arrowheads *d*. In this case, however, the coils *a*, *a'* are in reality acting as the primary of the transformer, and coil *b* is acting as the secondary; therefore, the resultant flux is in the direction indicated by arrows *e*. The line pressure is reduced by an amount equal to the counter electromotive force generated in coils *a*, *a'* plus a small amount for losses.

34. As an illustration, assume that the regulator is capable of raising or lowering the voltage of a 100-volt, 100-ampere circuit 10 per cent., and that there are no losses in the regulator itself. In Fig. 20 (*a*), the alternator is supplying 100 amperes at 100 volts, and the regulator is raising the feeder voltage to 110. In order that there shall be no loss of power, the current in the feeder circuit must be 90.91 amperes, leaving 9.09 amperes to flow through the primary coil. In (*b*), with the exception of the very small magnetizing current that flows through the primary coil, the voltage and the current are the same on both sides of the regulator. In (*c*), the feeder voltage is lowered to 90, and the current must therefore be raised to 111.11 in order that there shall be no losses. This leaves 11.11 amperes to flow backwards through the primary coil.

In (*a*), the primary coil is in the position of maximum boost, and the short-circuited coil *b'* is inactive. In (*b*), the primary coil is inactive, or the core is in the neutral position, and the short-circuited coil has its maximum effect. In (*c*), the primary coil is in the position of maximum lowering, and the short-circuited coil is inactive. The core may be left in any intermediate position between the three shown, so that

any effect from maximum boost to maximum lowering may be obtained. None of the flux set up by the primary winding can pass through the short-circuited coil. The only flux passing through this coil is that set up by the secondary coil or a portion of it, the portion depending on the position of the armature.

As the armature is turned from the position of either maximum boost or maximum lowering to neutral, the influence of the primary coil on the secondary diminishes and at the same time the current in the short-circuited coil increases, so that the total ampere-turns on the armature acting in opposition to those on the secondary are always approximately equal to those on the secondary. The operation of the short-circuited coil does not increase the losses in the regulator, but rather tends to keep them constant for a given secondary current.

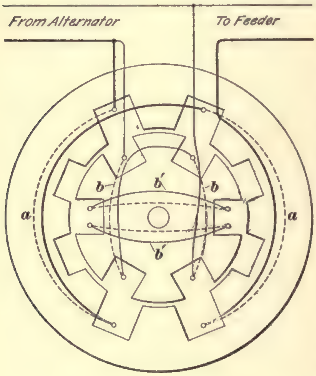


Fig. 21

35. Fig. 21 illustrates the method of placing the windings in a General Electric I R S type, single-phase, induction regulator. The secondary winding *a* is placed in slots on the inside circumference of the stationary shell, and the primary winding *b* and the short-circuited winding *b'* in slots on the movable armature core.

Fig. 22 shows the principal parts of a B R type regulator. The secondary coil *a* is shown in the interior of the shell, while the primary coil *b* and the short-circuited coil *b'* are shown in position on the armature core. When assembled, the end of the armature shaft projects through the hole *c* in the cover, and the worm-wheel segment *d* is keyed to the projecting end. This segment engages with a worm on the

shaft *e*. This shaft may be turned either by a hand wheel or by means of the small motor *f* through a worm-wheel on the end of the shaft *e* and a worm on the extension of the motor shaft. When it is desired to operate the regulator by hand, the motor worm-gear may be easily disengaged.

36. The motor may be hand-controlled by a small double-pole, double-throw switch mounted at any convenient point on the switchboard and so wired that the motor may be started in either direction by throwing the switch the proper way. A limit switch *g*, Fig. 22, mounted on top of

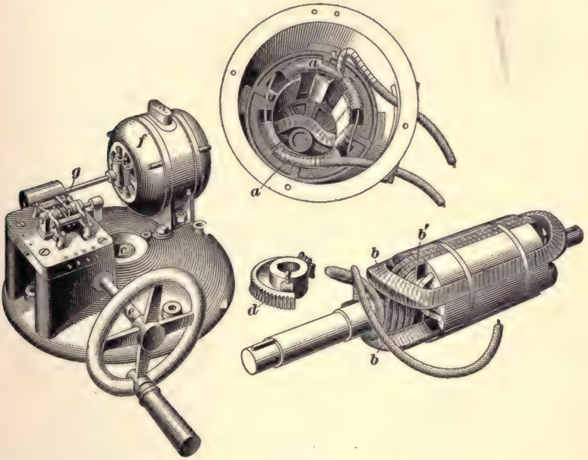


FIG. 22

the regulator, opens the circuit when the regulator has reached the limit of its travel in either direction. The limit switch automatically closes as soon as the regulator recedes from its extreme position. A separate limit switch is provided for each direction of rotation, and the fact that either has opened does not prevent the motor from operating in the reverse direction through the other one. A brake which is held off by a magnet so long as current is flowing through

the motor, is set by force of gravity as soon as the current ceases to flow, and the motor is stopped at once.

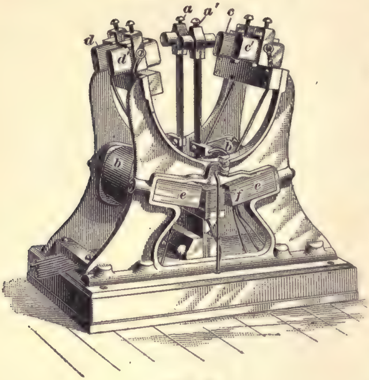


FIG. 23

For automatically controlling the motor, a potential relay is used to detect variations of voltage. The potential relay closes a circuit through an electrically operated relay switch, shown in Fig. 23. This switch has two movable contacts a, a' and two magnets b, b'. When magnet b is energized, the contacts are forced against the carbon blocks c, c' on one side, and when the magnet b' is energized, the contacts are forced over to the blocks d, d'. The magnet cores e and the armature f are laminated for use with alternating current.

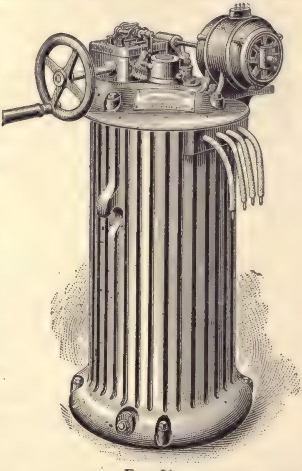


FIG. 24

37. In Fig. 24 is shown a complete single-phase, oil-insulated induction regulator, and in Fig. 25 is shown the connections for automatic operation. The motor may be of either the direct- or the alternating-current type, but connections are shown for a three-phase, alternating-current motor run from a low-tension circuit. One wire of the three-phase circuit leads

direct to the motor; another leads both to the potential-relay contact lever and to one of the middle contacts *a* of the relay switch; while the third wire leads to the other middle contact *a′* of the relay switch and to both of the relay-switch

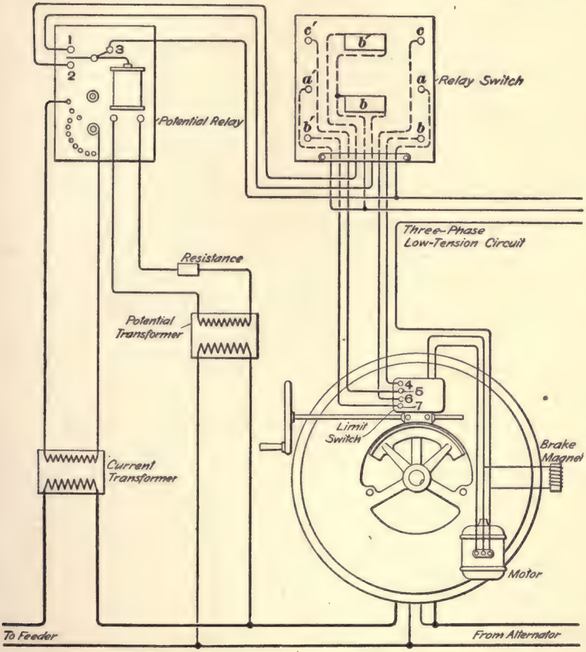


FIG. 25

magnets *b*, *b′*. These magnets are also connected, respectively, to contacts *1* and *2* on the potential relay.

When the voltage at the distant center of distribution is normal, the lever on the potential relay remains midway between contacts *1* and *2*, as shown in the figure. If the voltage becomes too low, the lever touches contact point *1*,

thus closing the circuit through magnet *b*. This causes contacts *a*, *a'* to tip over against carbon blocks *c*, *c'*, and starts the motor in a direction to make the regulator boost the feeder voltage. If the load on the feeder is reduced and the voltage at the center of distribution becomes too high, the lever on the potential relay touches contact *2*. Magnet *b'* on the relay switch is thereby energized, and the switch closes to contacts *b*, *b'* and starts the motor in a direction to make the regulator reduce the line voltage.

Whichever way the motor is operating, the potential relay opens the circuit through it as soon as the voltage reaches normal; or, if for any reason the relay does not open the circuit until the regulator has reached the limit of its travel, the limit switch opens. In any case, as soon as the circuit through the motor is opened, the magnetic brake promptly stops the motion of the regulator, so that no *hunting*, or running back and forth of the regulator, occurs.

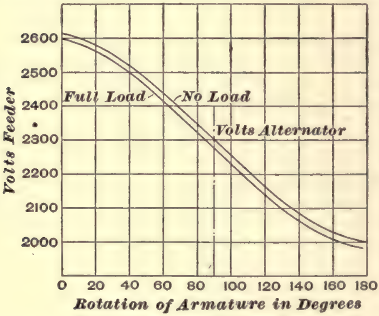


FIG. 26

38. The effect of turning the regulator armature from the position of maximum boost through 180° to the position of maximum lowering is shown in Fig. 26. The regulator on which the tests were made for these curves was capable of either boosting or lowering the feeder voltage 300 volts, or a total variation of 600 volts. The normal alternator voltage was 2,300. The maximum variation produced by the regulator was therefore 26 per cent.; that is, 13 per cent. each way from normal.

A single-phase induction regulator can be used on any two-wire, alternating-current circuit, whether the supply comes from a single-phase alternator or from one phase of

a polyphase alternator. With the potential relay adjusted to make contacts at the proper time, the regulator located at the station will automatically maintain the voltage practically constant at any desired point on the feeder circuit.

39. Polyphase Regulators.—Polyphase induction regulators are built on exactly the same principle as the single-phase regulator just described. There are, however, as many primary, or shunt, windings as there are phases. These shunt windings are identical in every way, and are distributed in slots on the movable core, Fig. 27, in a manner very similar to the distribution of the windings in

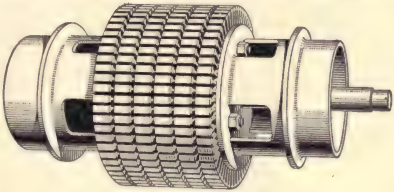


FIG. 27

the field slots of an induction motor. The arrangement is such that any given pole has as many distinct and separate windings as there are phases.

The magnetizing flux produced by the primary, or armature, is practically constant in value, but rotates similar to the field flux of an induction motor. The armature itself does not rotate, except when it is turned either manually or automatically through short arcs for purposes of regulation.

40. The secondary windings are distributed in slots on the inner circumference of the stationary shell, a view of which is shown in Fig. 28. A separate and distinct secondary winding is connected in series with each line of the alternating-current circuit. All the series windings are alike and are symmetrically arranged, similar to the primary windings. The magnetizing effect of the secondary winding, therefore, is also rotating. If the armature is in such a position that similar poles of the two rotating magnetisms

are opposite each other; that is, a north pole on the shell opposite a north pole on the adjacent face of the armature, the effect of the regulator is to boost the feeder voltage. If the poles of the rotating-field magnetism of the secondary windings agree in direction with the poles on the adjacent faces of the armature; that is, a north pole opposite a south pole, the effect of the regulator is to lower the feeder voltage. Any intermediate effect may be obtained by leaving the armature in a position midway between the positions of maximum boost and maximum lowering.

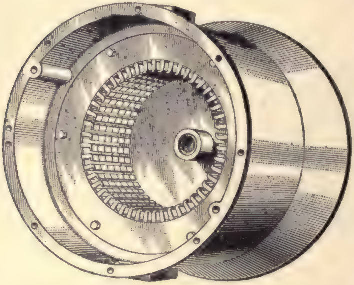


FIG. 28

41. Polyphase induction regulators are much used on transmission circuits leading to substations in which rotary converters are employed. The regulators can be installed either in the main station or in the substation. Rotary converters are generally used to supply direct current to street-railway lines. The pressure drop on street-railway feeder circuits varies a great deal on account of the widely varying current taken by the car motors. Automatic polyphase induction regulators may be so connected that they will automatically adjust the alternating electromotive force supplied to the converters, so as to compensate for the drop in the direct-current feeders and to keep the voltage at the cars approximately constant.

Single-phase feeders sometimes lead from substations to lighting circuits. The use of polyphase regulators in the circuits leading to the substation and single-phase regulators in the two-wire lighting feeders will give almost perfect regulation at the lamps.

MODERN ELECTRIC-LIGHTING DEVICES

LUMINOUS EFFICIENCY

1. Electric lamps are devices for transforming electric energy into light. Most arc and incandescent lamps, however, radiate as light only a very small proportion of the energy supplied them; a large part of the energy is radiated as heat. Any source of light may be considered as giving out two kinds of radiation—luminous and obscure. The radiated energy sets up vibrations in the ether, and those vibrations which have a wave length lying between certain limits are capable of affecting the eye and producing the sensation known as light. All vibrations lying above or below these limits are useless so far as producing light is concerned. If A is called the total radiation from a light-giving source, B the amount of luminous radiation, and C the non-luminous, or obscure, radiation, then $A = B + C$, and the ratio $\frac{B}{A}$ is the **optical,** or **luminous, efficiency** of the light-giving source, because it is the ratio of the radiation that is useful in producing light to the total radiation. The efficiency of ordinary light-giving sources, as measured by this standard, is very low. For example, the luminous efficiency of ordinary incandescent lamps is only a fraction of 1 per cent. and that of the best arc lamps less than 10 per cent.

There is room for a great deal of improvement in the efficiency of light-giving sources, and efforts to effect such improvement have been made largely with a view to finding

an illuminant in which a higher temperature can be attained without injury to the material used. Generally, the higher the temperature of a light-giving source the higher is its luminous efficiency. All substances, however, do not have the same luminous efficiencies at equal temperatures; a lustrous, metallic surface radiates as light a larger proportion of its total radiated energy at a given luminous temperature than does a black surface, such as carbon, at the same temperature.

INCANDESCENT LAMPS

METALLIZED-FILAMENT LAMPS

2. The first incandescent lamps made were very crude indeed compared to those now in use. The principle on which the lamps operate—namely, the heating to incandescence of a body in a vacuum by passing an electric current through it—has not changed, but there have been many improvements in the processes of manufacture, especially in the method of producing the vacuum and in the methods of making the bodies, or filaments, to be heated. Better materials from which to make the filaments have been found, so that while the first lamps consumed a great deal of energy and gave off but little light, later ones have greatly reduced the energy consumption and increased the light output.

The ordinary carbon-filament incandescent lamps usually consume, when new, from 3.1 to 3.5 watts for each candlepower given off. If a larger current were forced through the filaments by increasing the pressure, the candlepower would increase much more than the consumption of energy; that is, the efficiency of the lamps would be increased. These lamps, however, are soon destroyed if run at too high temperature.

3. Preparation of Metallized Filaments.—Ordinary carbon filaments are made by squirting a solution of cellulose through a die and letting it fall in fine threads into wood alcohol, which hardens the cellulose. The fibers are then dried, shaped into the desired form for the lamp, placed in a

muffle, and heated to the highest temperature attainable with a gas flame. They are thereby carbonized and are then known as *base filaments.* After being prepared in this manner, they are hung in a chamber, from which the air is exhausted and a thin vapor of gasoline substituted, and are heated to incandescence by passing an electric current through them. A dense layer of carbon from the decomposing gasoline vapor forms on the filament. This process is called *treating*, or *flashing*, the filaments, after which they are ready for mounting in the lamps.

Although heating carbon filaments to a high temperature by passing a current through them injures or destroys them, it has been found that subjecting them to an excessively high temperature by the application of heat from an outside source causes them to undergo a change that greatly improves their characteristics for lamp filaments. In the new process, the filaments, in their basic form, are packed in a cylindrical carbon box, which is fed into the end of a carbon tube. To the ends of the tube are attached water-cooled copper clamps, by way of which a large electric current is sent through the tube after it has been buried in powdered carbon. The passage of the current through the resistance of the carbon tube raises the temperature inside the tube to between 3,000° and 3,700° C. The carbon tube as thus used is a form of *electric-resistance furnace.* After the filaments have been fired in this manner for a short time, they are cooled, treated in gasoline vapor, and again fired in the electric furnace. This process leaves the filaments covered with a shell of lustrous, steel-gray elastic carbon in an almost pure graphite form, and they are then ready for use in the lamps.

4. The ordinary carbon filament has a negative temperature coefficient; that is, its resistance decreases as its temperature increases, thus making it very sensitive to changes of voltage. Filaments that have been subjected to the intense heat of the electric furnace, as just described, have a positive temperature coefficient. The new filament also has a lower resistance than the older carbon filaments; in fact, when the

filaments are finally removed from the electric furnace their characteristics resemble more nearly those of metal than of carbon, hence the name **metallized filament.** The word *graphitized*, also sometimes used, more nearly describes the actual condition.

Metallized-filament incandescent lamps have the same general appearance as the ordinary incandescent lamp, except that they are made only in the larger sizes and some of the bulbs are tipless. The standard sizes consume 50, 100, 125, 187, and 250 watts, respectively, and give off approximately 1 candlepower for each 2.5 watts consumed. By the use of suitable reflectors the light can be thrown in any desired direction, so that the concentrated candlepower is much greater than 1 for each 2.5 watts.

5. Operation of Lamps.—The metallized filaments can be operated at a much higher temperature than the ordinary carbon filaments; they have also a more lustrous surface, offering better properties for radiating light. They can therefore be operated at a higher efficiency and can also be made to produce a whiter light, more nearly resembling sunlight. In spite of the higher efficiency, these lamps have a length of useful life about the same as that of the ordinary carbon-filament 3.1-watt lamp. Because of the lower resistance of the filament, lamps with metallized filaments are not at present made in as small units for standard voltages as are those having the ordinary carbon filaments.

6. The difference in the color of light given off by ordinary carbon filaments when burning under various conditions is approximately as follows:

Color of Light	Watts per Candlepower
Clear white	1.5
White, very faintly tinged with yellow	2 to 2.5
Yellowish white	3
Yellowish	3.5
Yellowish, tinged with orange	4
Orange yellow	4.5
Distinctly orange red	5

The clear white light, which most nearly resembles sunlight, is the most desirable; hence, the advantage of operating at high efficiency is twofold—increased economy and better light.

7. The objection to operating lamps with ordinary carbon filaments at a consumption per candlepower of less than from 3 to 3.5 watts may be seen from the following data of a 16-candlepower carbon-filament lamp. The figures in the first line are the watts per candlepower and those beneath, the corresponding useful life in hours. The less the consumption per candlepower the shorter the life.

2.0	2.5	3.0	3.5	4.0	4.5	5.0
28	132	412	1,000	2,005	3,570	6,125

8. The economy in using the higher efficiency metallized-filament lamps may be readily estimated. A 3.1-watt 16-candlepower carbon-filament lamp consumes in a useful life of 500 hours $3.1 \times 16 \times 500 = 24{,}800$ watt-hours, or 24.8 kilowatt-hours. A 2.5-watt 16-candlepower metallized-filament lamp consumes in the same time $2.5 \times 16 \times 500 = 20{,}000$ watt-hours, or 20 kilowatt-hours,—4.8 kilowatt-hours less than the carbon-filament lamp. At the prices usually charged for power for lighting purposes—from 10 to 15 cents per kilowatt-hour—from 50 to 75 cents is saved during the life of a lamp in the cost of power consumed for each 16 candlepower given off. However, the smallest metallized-filament lamp made consumes 50 watts and gives off 20 candlepower, so that instead of effecting a saving, the usual result of the improvement will be to obtain more light at practically the same cost as before.

METALLIC-FILAMENT LAMPS

9. In the effort to find a more efficient substitute for carbon for the filaments of incandescent lamps, much experimenting has been done with metals having a very high melting point. Certain rare metals, notably tantalum, osmium, and tungsten, have been found so well adapted for incandescent-lamp filaments that some surprising results

have been obtained. It is now possible to make metallic-filament lamps that can be operated at even higher efficiency than the graphitized-filament lamps, and that have a useful life fully equal to and in some cases exceeding that of the carbon lamps.

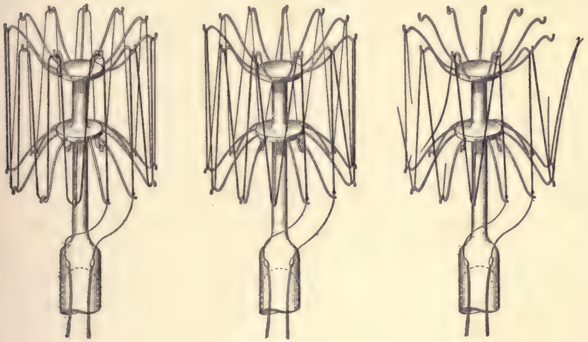
TANTALUM LAMPS

10. Tantalum.—The first metallic-filament lamp to come into commerical use was the **tantalum lamp.** Tantalum is a comparatively rare metal of which little was generally known until Doctor Von Bolton, a German investigator, found that it possesses very valuable characteristics for incandescent-lamp filaments. The metal is very heavy, having a specific gravity of 16.8; that is, a piece of tantalum is 16.8 times as heavy as an equal volume of water. As the specific gravity of lead is only 11.36, tantalum is nearly one and one-half times as heavy as lead. Tantalum is malleable and ductile; it can be hammered out into thin sheets, but being as hard as mild steel, the pounding must be severe; it can be rolled into very fine wire, which is stronger than steel. The melting point of tantalum is very high—nearly 2,300° C.—and, with the exception of hydrofluoric, no acid, even when boiling, will affect it. Tantalum also has very high electric resistance and expands but little when heated; its resistance increases as the metal is heated; that is, it has a positive temperature coefficient. However, the resistance of tantalum is lower than that of carbon; hence, tantalum lamp filaments are made longer than carbon filaments for the same voltage.

11. Supporting Tantalum Filaments.—The low resistance of the metal makes it necessary that tantalum filaments, in all except the very low voltage lamps, be very long. For example, the filament in a 22-candlepower 44-watt 110-volt tantalum lamp is 20 inches long and has a diameter of .0018 inch. In spite of the high specific gravity of tantalum and the great length of a lamp filament made of this metal, the extremely small diameter makes a

filament so light that it requires 20,000 of the 22-candlepower filaments to weigh 1 pound.

The length of the filament, together with the fact that it stretches when hot, makes its support in the bulb a somewhat difficult matter. The device generally adopted is shown in Fig. 1. A central glass rod bears two glass supporting rims, from which project laterally evenly spaced



(a) (b) (c)

FIG. 1

arms made of nickel wire and having hooks at the ends over which the tantalum filament is wound. The ends of the filament are connected to the lamp socket by platinum leading-in wires. The upper support has eleven arms and the lower one twelve, each upper arm being in a vertical plane midway between the vertical planes of the two adjacent lower arms, so that the filament winds on in a zigzag fashion.

12. Characteristics of Tantalum Filaments.—The tantalum filament when new has a perfectly smooth cylindrical surface, but as it ages the surface presents a peculiar glistening appearance, which, under the microscope, appears rough and pitted. For the first few hours of service, the filament stretches and hangs loosely on its supports, but as it grows older it contracts until it is shorter than at first.

Fig. 1 (*a*) shows the appearance of a new filament, which is drawn in loose, easy curves over the hooks, while (*b*) shows the appearance of a filament after being in use for some time, the loops being drawn down to sharp-pointed angles. The filament finally breaks, but wherever the loose ends come in contact with some other portion of the filament they immediately weld fast and the lamp continues to burn, often with increased candlepower; the filament is shortened, owing to the cutting out of a portion of its length, and its resistance is thereby decreased, but, of course, this shortens the remaining life. Quite frequently, even after the filament has been broken several times, tantalum lamps continue to give good service for a time. Fig. 1 (*c*) shows the filament on one side of a lamp after it had broken three times and still continued to do good service. For the sake of clearness the filament connections on the back of the lamp are omitted.

While new tantalum wire is very strong, it loses much of its strength and becomes brittle after having served 200 or 300 hours as a lamp filament; hence, while new tantalum lamps may be handled as freely as carbon-filament lamps, they should not be disturbed after having been in service a while. It also follows that they are not suitable for use where there is much vibration.

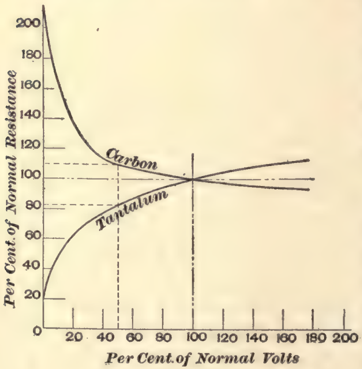


FIG. 2

13. The curves in Fig. 2 show the comparative resistance characteristics of carbon and tantalum filaments, assuming that the resistances are the same at 100 per cent. of normal volts. When the voltage is zero, that is, when the filaments are cold, the resistance of the tantalum filament is only

20 per cent. of its value at normal voltage, while that of the carbon filament is about 225 per cent. As the volts are increased, thereby forcing a current through the filaments and heating them, the resistance of the tantalum filament increases, while that of the carbon filament decreases, as shown by the curves; for example, at 50 per cent. of normal voltage, the resistance of the tantalum filament is about 82 per cent. of normal, and that of the carbon filament about 108 per cent.

This resistance characteristic of the two filaments shows that a tantalum-filament lamp will take much the greater current at starting, that it will reach incandescence more quickly, and that it will be much less sensitive to slight variations of the supply voltage; for, as the volts increase, the resistance also increases, thus tending to keep the current through the filament more nearly constant.

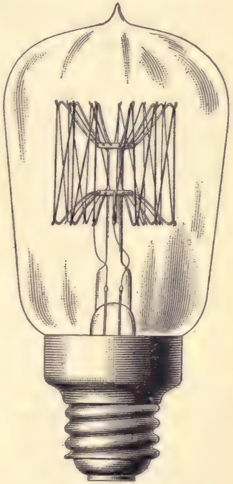


Fig. 3

14. Fig. 3 shows a complete 22-candlepower tantalum-filament lamp having a consumption of 44 watts, or 2 watts per candlepower, and an average life of about 700 hours. This lamp is now supplied by United States manufacturers for any voltage from 100 to 130. The bulb is very nearly the same size as that of the ordinary 16-candlepower carbon-filament lamp.

15. Fig. 4 shows the results of comparative tests of several tantalum lamps and one carbon-filament lamp. Curves *a* and *b* show the increase of specific consumption with age; the values of the ordinates, in watts per candlepower, are given on the right-hand margin. The tantalum lamps consumed an average of 1.85 watts per candlepower

at the start, 2.2 watts at the end of 700 hours, and 2.6 watts at the end of 1,200 hours. The corresponding figures for the carbon-filament lamp were 3.3, 3.7, and 3.9 watts per candlepower.

Curves *c* and *d* show the decrease of candlepower with increasing age; the values of the ordinates are given on the left-hand margin. The tantalum lamps gave off about

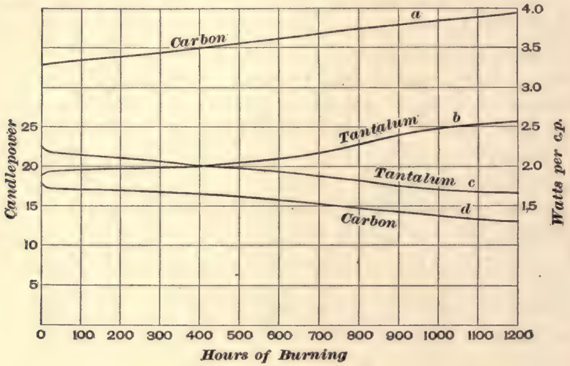


FIG. 4

22 candlepower at the start, dropped 20 per cent., or to 17.6 candlepower, in about 850 hours, and were still giving an average of nearly 17 candlepower at the end of 1,200 hours. The carbon lamp began with about 17 candlepower, burned over 900 hours before losing 20 per cent., and was giving about 13 candlepower at the end of 1,200 hours. This carbon lamp was evidently an exceptionally good one.

OSMIUM LAMPS

16. Lamps with filaments made of the very rare metal **osmium** are used to some extent in European countries, and if the claims made for them are substantiated in practice and their cost is not excessive, they will probably come into quite general use. The lamp was invented by Doctor Welsbach, of Vienna, the originator of the Welsbach gas mantle.

17. Preparation of Osmium Filaments.—Osmium has a specific gravity of 22.48, about twice that of lead; it also has a very high melting point, in fact it is almost infusible. This metal is malleable and ductile and possesses high electric resistance. Osmium lamp filaments, however, are not produced by drawing the pure metal into fine wire as is done with tantalum filaments. One process is to mix finely divided osmium into a thick paste and then, under heavy pressure, force this paste through dies, shaping the threads thus formed into loops and heating them in a vacuum. The threads then

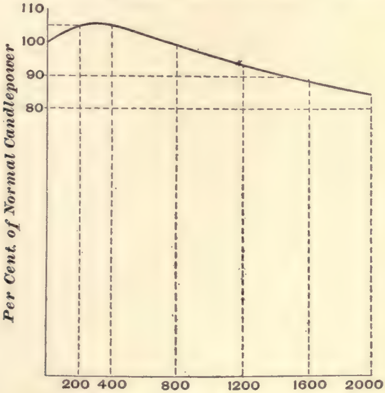


FIG. 5

consist of porous, rough osmium with a considerable percentage of carbon. To burn out the carbon, the filaments are next placed in an atmosphere containing steam and other gases and heated by passing an electric current through them. This is called *forming them*, and after this process they consist of pure porous osmium, in which condition they are mounted in the lamps.

18. Operation of Osmium Lamps.—After the lamps are put in service, the surface of the porous filaments becomes gradually more and more smooth, resulting in an increase of light during the first 200 or 300 hours. Fig. 5 shows the

variation of candlepower, with life, of a 44-volt 32-candlepower osmium lamp. Beginning at 100 per cent. (32 candlepower), the light increases until at the end of 250 hours it is about 105 per cent. (33.6 candlepower). From this point the candlepower gradually decreases, but at the end of 2,000 hours it has dropped only to about 85 per cent. of its original value.

It is not certain that all osmium lamps will have as long life as the one whose life curve is shown in Fig. 5, although the claim is made that with an initial consumption of 1.5 watts per candlepower some of the lamps burn even 5,000 hours without losing more than 20 per cent. of their original candlepower. Of twelve lamps tested in Vienna, the average life was 2,220 hours, the shortest being 1,793 and the longest 3,036 hours, respectively, and during this test only three of the lamps lost more than 10 per cent. of their original candlepower. The average consumption during life was from 1.8 to 2 watts per candlepower. The British General Electric Company guarantees their osmium lamps for a life of not less than 500 hours with a consumption of 1.5 watts per candlepower.

19. Osmium lamp filaments when incandescent become quite flexible, and if the lamp is in a horizontal or an inclined position, the filaments, unless well supported, tend to droop, or sag, under their own weight. Moreover, the filaments are somewhat more fragile than carbon filaments and are more likely to become damaged in transportation. They are made in long **U**-shaped loops, which are so anchored to a glass rod projecting into the bulb from the base that the lamps can be burned in any position. The filaments do not, however, become so brittle with use as the tantalum filaments, and are more suitable for use where there is vibration. In fact, osmium lamps have given satisfactory service in car lighting.

Osmium has a positive temperature coefficient; hence, osmium lamps are not sensitive to slight variations of voltage. In fact, they will stand a considerable increase above their normal voltage without serious injury. Osmium lamp filaments also weld together when broken, similar to tantalum filaments.

TUNGSTEN LAMPS

20. Tungsten, sometimes called *wolfram*, is one of the so-called rare metals, though it occurs more plentifully than either tantalum or osmium. Tungsten is steel gray in color, so hard that it will scratch glass, and very heavy (specific gravity 19.129). Like carbon, tungsten changes directly into vapor at a very high temperature (considerably higher than the corresponding temperature for carbon) without passing through a liquid state. Its specific resistance is lower than that of carbon; hence, tungsten lamp filaments must be very long and very thin, as is the case with all metallic filaments.

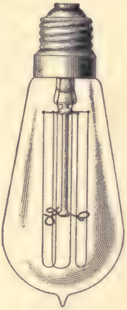


FIG. 6

21. Tungsten lamps were first produced in Europe by German and Austrian inventors. The filaments are made by two or three methods and, in some types of lamps, consist of an alloy of osmium and tungsten. On account of the difficulty of properly supporting a long, slender filament, the lamps are not made in small sizes or for high voltages. The appearance of the tungsten lamp first placed on the American market is shown in Fig. 6. This lamp was invented by Dr. Alexander Just and Franz Hanaman, and is called the Just tungsten lamp; it is standardized at 40 hefner candlepower with a consumption of 40 watts at 100 to 120 volts, and has a useful life of 1,000 hours.

22. Operation of Tungsten Lamps.—Well-authenticated tests made in public laboratories in Germany and Austria indicate that the performance of tungsten lamps, when compared with that of carbon-filament lamps, is remarkable. A useful life of from 1,500 to 2,000 hours at less than 1 watt per candlepower is indicated. Lamps working at .75 watt per candlepower have been run from 1,000 to 1,100 hours with a loss of only 3.5 per cent. of their light output, and for 1,600 hours with a loss of 20 per cent.

The curves in Fig. 7 shows the results of official tests made on the *osram lamp*, which has a filament consisting of an alloy of osmium and tungsten. The curves in (*a*) show the change of total candlepower of two lamps of about 28 and 32 hefner units, respectively, and those in (*b*) show the change in watts per hefner. The light output increases in each case during the first 200 hours, and the consumption per hefner decreases; the output then falls off gradually, but has fallen only 5 or 6 per cent. below the initial candlepower at the end of 1,000 hours. The specific consumption has meanwhile risen to a little less than 1.2 watts per unit.

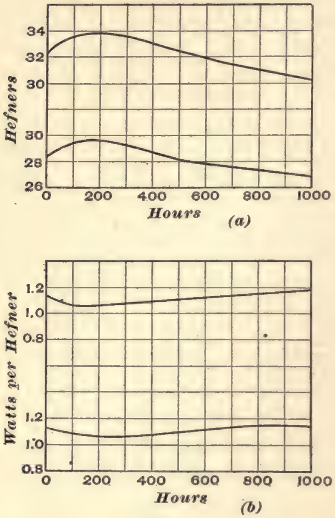


FIG. 7

23. Tungsten lamps work equally well on either direct or alternating current and are not sensitive to changes of voltage; in fact, the voltage can be doubled without injuring the lamps. Some types of tungsten lamps can be used in any position and are not affected by vibration, unless it is very excessive. Table I shows the effect of gradually raising the voltage on a 17-candlepower 20-volt tungsten lamp. At the end of the test the lamp seemed uninjured.

The light from these lamps is exceedingly white and pleasant, but the lamps are so very brilliant that frosted bulbs or some form of shades are necessary. Owing to the greater abundance of tungsten as compared with other rare metals used for lamp filaments, and also because of their high

economy and long life, tungsten lamps are likely to come into more extensive use than the other metallic-filament lamps.

TABLE I

TUNGSTEN LAMP TESTS

Volts	Amperes	Candlepower	Watts per Candlepower
20.2	.970	17.1	1.138
25.8	1.140	56.9	.670
32.7	1.300	88	.484
34.5	1.340	110	.421
39.0	1.440	158	.355
40.6	1.475	185	.322

24. Normal Filament Temperatures.—Table II gives the approximate true temperatures of some incandescent lamps as determined by the United States Bureau of Standards, Washington, D. C.

TABLE II

NORMAL BURNING TEMPERATURES

Type of Lamp	Watts per Candlepower	Volts	Approximate True Temperature Degrees C.
Carbon	4	50	1,800
Carbon	3.5	118	1,850
Carbon	3.1	118	1,950
Tantalum . .	2	110	2,000
Tungsten . .	1	100	2,300

THE NERNST LAMP

25. In the incandescent lamps thus far considered the glowing body, or filament, is enclosed in a vacuum, because in open air it would be oxidized, or burnt up, by the oxygen in the air. The **Nernst lamp** is properly called an incandescent lamp, because the light-giving portion is a solid body heated to incandescence by the passage of electric current. This lamp is the result of researches made by Dr. Walter Nernst, a German scientist. The distinguishing features of the lamp are its filament, or glower, the means for making the glower conductive, and the fact that the glower operates in the open air.

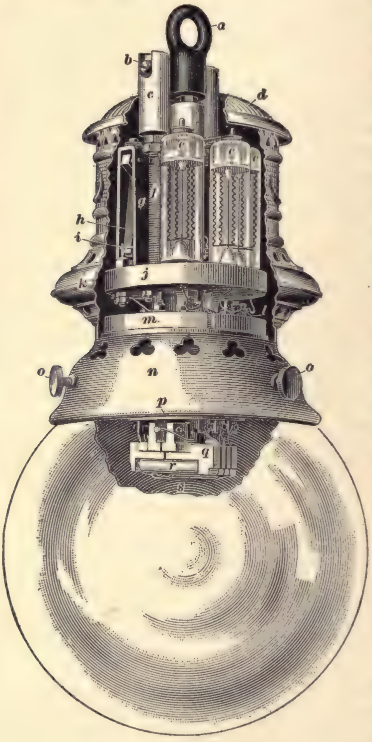


Fig. 8

26. Essential Parts of the Nernst Lamp.—The essential parts of the Nernst lamp are: (1) the *glower*, or light-giving portion; (2) the *heaters*, which raise the temperature of the glowers at starting until they become conductors; (3) the resistance, or *ballast*, as it is

termed by the manufacturers, which steadies the current through the lamp; and (4) the *cut-out device* for opening the circuit through the heaters after the lamp has been started. All these parts are compactly assembled and enclosed in a case having a suspension hook, or screw base, and an enclosing globe attached. Fig. 8 is a view of a medium-sized Nernst lamp, partly in section, showing the location of each part, as follows:

a, the suspension eye;
b, a lamp terminal;
c, the terminal porcelain;
d, the iron cap covering the lamp;
e, ballast tubes;
f, the cut-out coil;
g, an armature support;
h, an armature;
i, a silver contact stop;
j, the ballast porcelain;
k, the lamp case, or housing;
l, an aluminum plug;
m, the porcelain contact sleeve;
n, the lamp petticoat;
o, globe-holding screws;
p, the holder base;
q, the holder;
r, a heater tube;
s, a glower.

27. Nernst Glowers.—The **glowers,** or light-giving portion of the Nernst lamp, are made by pressing through suitable dies a dough composed of an oxide of some of the rare metals, such as thorium, zirconium, yttrium, etc. The porcelain-like strings issuing from the dies are dried, cut into suitable lengths, and baked. Terminals are then attached by soldering wires to beads of platinum embedded in the ends of the glower. Embedding the platinum beads in the ends of the glower is found to be preferable to wrapping platinum wire around the ends, because as the glowers shrink in service the beads are gripped tightly, while the wire wrappings become loosened. The process of making the glowers was the most troublesome feature in developing

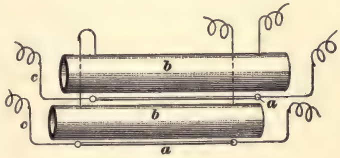


FIG. 9

the lamp, and finding a suitable method of attaching the terminals was especially difficult.

Fig. 9 shows a pair of glowers *a* and their accompanying heater tubes *b*. Platinum terminal wires *c* are attached to the glowers, and to the ends of these wires are fastened short copper wires. The copper wires terminate in small, tapered aluminum plugs (not shown in this figure) suitable for insertion in receptacles on the porcelain base on which the heater tubes and glowers are mounted.

28. The glowers have an extremely high resistance when cold, or at ordinary temperatures, that is, they are insulators; but when warmed, the resistance decreases as the temperature rises until the glowers become good conductors at about 600° or 700° C. The curve in Fig. 10 shows the relation that exists between the temperature of a Nernst

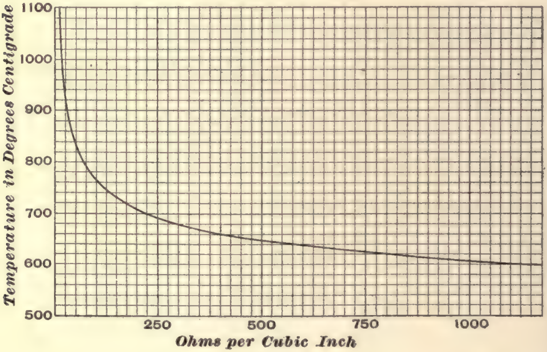


FIG. 10

glower and its specific resistance. At 600° C., the specific resistance is about 1,200 ohms per cubic inch, while at lower temperatures it is much greater. As the temperature rises above 600° C., the specific resistance lessens very rapidly, being about 225 ohms at 700° C. and decreasing to about 30 ohms at 900° C.

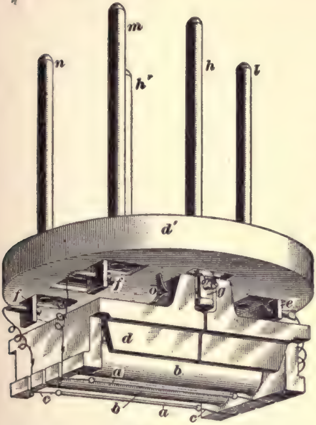


FIG. 11

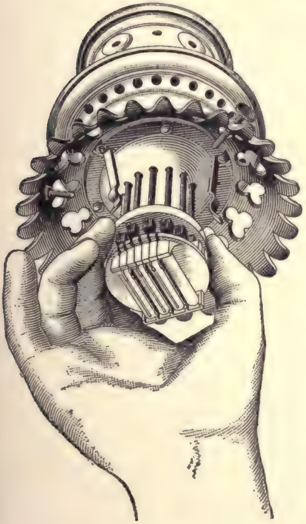


FIG. 12

29. Nernst Heaters. Various devices have been tried for raising the temperature of the glowers to the point where they become conductors. In the United States, the plan now followed is to wind fine platinum wire over thin porcelain tubes, and then cover the wire with a cement paste that will withstand the intense heat of the glowers when in operation and that also affords a white surface to reflect the light downwards.

Fig. 11 shows the glowers *a* and the heaters *b* of a two-glower lamp mounted in their porcelain holder *d*, which is attached to the porcelain base *d'*. The glowers, located just beneath the heater tubes, are connected to the brass pieces *e*, *f* attached to the base. The terminals of the heater coils are connected by way of the brass pieces *g* (one on each side of the base) to the prongs *h*, *h'*. Prongs *l*, *m*, and *n* are connected with brass pieces *e*, *f*, thereby forming the terminals of the glowers. The holder is

secured to the base by cotter pins *o*, which are inserted through the brass pieces *g*. The portion of the holder facing the glowers is painted with a white enamel paste so that it will reflect light.

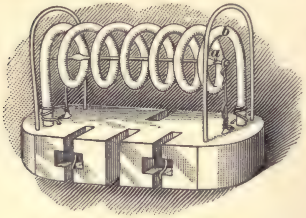


Fig. 13

Fig. 12 shows the method of inserting a holder, with its heaters and glowers, in a lamp. A six-glower unit with a suitable number of prongs is shown. The prongs enter receptacles with which they make the necessary connections. The hand should not be allowed to touch the glowers or heater tubes.

30. The smallest Nernst lamp, which is made to compete with the ordinary incandescent lamp and is fitted with a base for screwing into a standard Edison socket, has one glower surrounded by a helical-formed heater made of the same materials as the heater tubes for the larger lamps. Fig. 13 shows the appearance of the glower *a* and the heater *b* mounted on a porcelain holder, and Fig. 14 shows a complete lamp. This lamp gives about the same light as three ordinary 16-candlepower carbon-filament lamps.

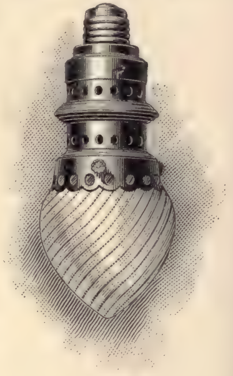


Fig. 14

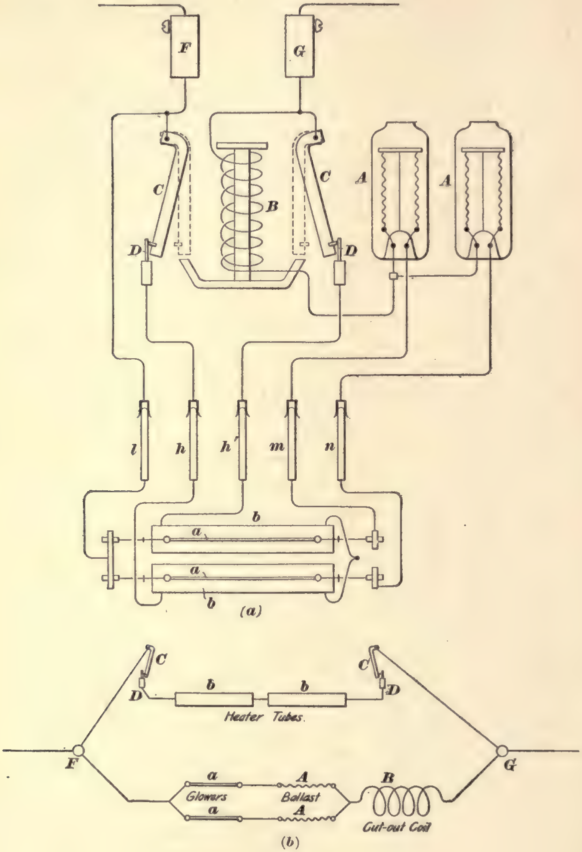
31. Ballast for the Nernst Lamp.—The rapid decrease of the resistance of the glowers with increasing temperature would render the lamps very unstable were it not for the **ballast**. If the glowers were connected directly across the circuit, they might be adjusted to work all right with a perfectly steady pressure; but any slight increase of

pressure would increase the current through the glowers and thus increase their temperature. The resulting decrease of resistance would permit still greater current to flow, and the process would continue until the glowers became practically a short circuit across the line.

The ballast consists of pure iron wire mounted in glass tubes (*e*, Fig. 8) from which the air is exhausted, the space then being filled with an inert gas, such as nitrogen. The resistance of iron wire rises very rapidly as the temperature of the wire increases. An increase of 10 per cent. in the current passing through one of these ballasts will cause as much as 150 per cent. increase in resistance. A small amount of resistance is therefore sufficient to insure stable operation, and the efficiency of the lamp as a whole is higher than if an ordinary resistance were used. By mounting the wire as described, all danger from oxidation, or burning of the wire, is removed, and the ballasts will last a long time, provided the voltage regulation is good.

32. Nernst Cut-Out.—The **cut-out** consists of an electromagnet connected in series with the glowers and arranged so that when current passes through them it will attract two armatures, one of which is shown at *h*, Fig. 8, and open the circuit through the heater coils.

33. Connections for Nernst Lamp.—Fig. 15 (*a*) shows a diagram of the connections of a two-glower lamp, and (*b*) shows the same connections in a simplified form. When current is first turned on to the lamp, it passes alternately from the terminals *F*, *G* through the armatures *C*, *C*, silver contact points *D*, *D*, prongs *h*, *h'*, Fig. 15 (*a*), to the heater coils *b*, *b*. As soon as the temperature of the glowers has risen enough to make them conducting, current also passes from the lamp terminals to the glowers *a*, *a* by way of prong *l* on one side, and the magnet *B*, ballast tubes *A*, *A*, and prongs *m*, *n* on the other side. When the current through the magnet has become large enough, the armatures *C*, *C* are drawn in by the magnetic attraction to the dotted positions, thus opening the circuit through the heaters at two points *D*, *D*.


F
G
A
A
C
C
B
D
D
l
h
h'
m
n
b
a
a
b
C
C
D
D
b
b
Heater Tubes.
F
G
a
A
B
Glowers
Ballast
a
A
Cut-out Coil

(a)

(b)

FIG. 15

The armatures are suspended loosely from a single point, so that they swing outwards against the contact points when the magnet is not excited; the single loose suspension also prevents humming, which would otherwise be caused by the alternating current in the coil. The temperature inside the lamp when operating is about 110° C., and to protect the wire of the cut-out coil from the heat, it is covered with cement.

34. Characteristics of the Nernst Lamp.—In Fig. 16 is shown a curve that illustrates graphically the flow of

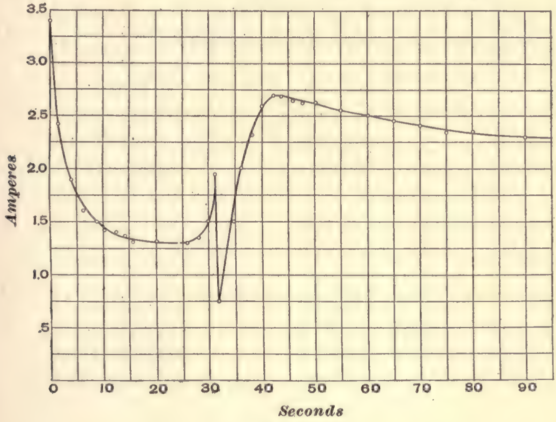


Fig. 16

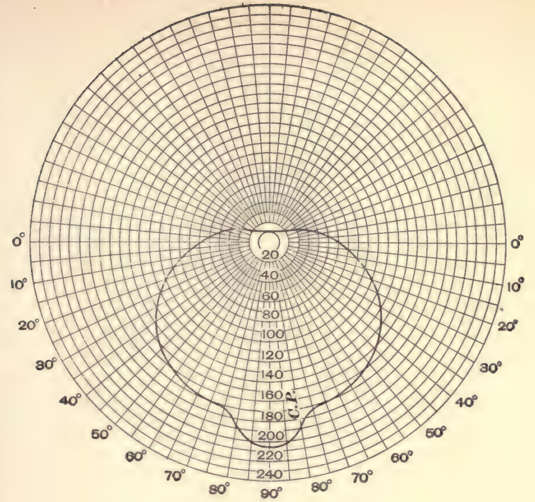
current through a six-glower 220-volt lamp from the time it is switched on until the lamp is running steady on its normal current—about 2.3 amperes. When first switched on, nearly 3.5 amperes flows through the heater tubes. The resistance of the platinum wire on the heaters quickly rises and brings the current down to about 1.3 amperes, which continues until at the end of 26 seconds the glowers begin to take current. The total current then gradually rises until, after a little over 30 seconds, the current in the glowers reaches a value high enough to cut out the heaters, when the total current

through the lamp decreases abruptly by the amount that the heaters were taking. The current through the glowers continues to increase, until at the end of about 40 seconds all the glowers are burning full brilliancy and the resistance of the ballast has risen enough to prevent further rise of current. From this time on there is a slight rise in the resistance of the ballasts, lamp connections, etc., until the whole lamp has reached its maximum temperature and the current has fallen to its normal value.

35. Nernst lamps are made with one, two, three, four, or six glowers, giving hemispherical candlepowers of very nearly 35, 75, 125, 190, and 300, respectively. The efficiencies of the lamps steadily increase with the number of glowers, the approximate consumption of energy in the various sizes in the order named being, respectively, 2.4, 2.2, 2.1, 1.85, and 1.75 watts per hemispherical candlepower. This increase in efficiency is due largely to the fact that the several glowers tend to heat one another.

The high efficiency of the Nernst lamp may be ascribed to the high temperature at which the glowers work, and to their ability to radiate a large proportion of the energy supplied them as light. The color of the light approximates closely to that of daylight, and hence is desirable for store or art-gallery illumination, where the correct determination of color is of importance. As an offset to these advantages, the Nernst lamp, in comparison with the incandescent lamp, is somewhat complicated, and high in first cost, although the parts to be renewed can be replaced at slight cost after the lamp is once purchased, because allowance is made for the scrap platinum in the burned-out parts. The slowness of starting is also a disadvantage for some kinds of illumination, particularly in theaters, or in any other place where it is desired to switch lamps on and off frequently.

36. The lamps are made for 110 or 220 volts alternating current; the 110-volt lamps can be adjusted for any voltage from 100 to 120, and the 220-volt lamps for any voltage from 220 to 240. For best results the voltage must not be


0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
20
40
60
80
100
120
140
160
180
200
220
240
C.P.
(a)

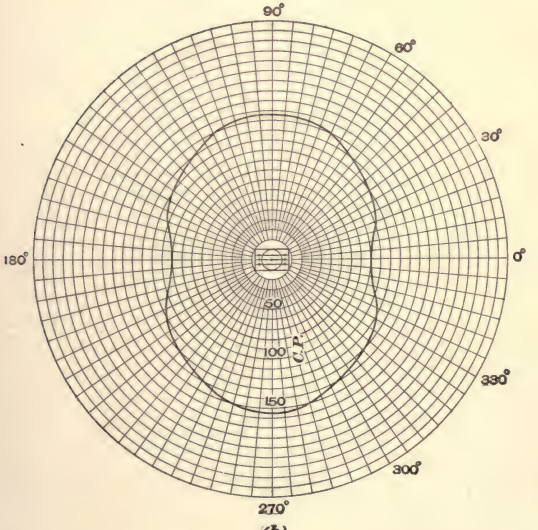

90°
60°
30°
0°
180°
330°
300°
270°
50
100
150
C.P.
(b)

FIG. 17

permitted to vary more than 3 per cent. above or below that for which the lamp is adjusted. Each 110-volt glower takes approximately .8 ampere, and each 220-volt glower, approximately .4 ampere. More satisfactory service is obtained from the 220-volt lamps. A single-glower lamp for outdoor service on series-circuits is also made. This lamp is made both for 26 volts 6.6 amperes and for 23 volts 7.5 amperes. All sizes, except the low-voltage series-lamp, are made in two styles, for either indoor or outdoor service, the difference being almost entirely in the style of casing used to enclose the lamp.

37. Light Distribution.—Owing to the reflecting surfaces just above the glowers, nearly all the light from a Nernst lamp is given off in the lower hemisphere. The light is very evenly distributed below the lamp in the vertical plane, as shown by the heavy curved line in Fig. 17 (*a*), where the candlepower given off in various directions by a three-glower lamp is indicated by the numbers in the vertical column. There is a slight excess of light immediately below the lamp. Fig. 17 (*b*) shows the horizontal distribution about a three-glower lamp; the light given off parallel to the glowers is much less than that given off perpendicular to them.

38. Care of Nernst Lamps.—Nernst lamps should have regular and systematic attention while in operation. There should be kept on hand a supply of parts likely to be needed, such as glowers, heaters, holders, ballast, glassware, etc., the number of extra parts depending on the number of lamps in use. The attendant should have a suitable kit of tools, and regular, systematic visits should be made to each lamp. He should carry with him a supply of parts most likely to be needed, including a number of repaired holders, complete with heaters and glowers, and should inspect each lamp as follows:

1. Determine whether all heater tubes become red when the current is turned on; if not, the holder should be replaced with a new one. After the lamp has been in use some time, the holder and heater tubes become blackened by a deposit

of oxide of platinum from the glower terminals. This deposit should be scraped off or a new holder substituted, so as to keep the reflecting surface good.

2. Inspect lighted lamps with colored glass to determine condition of glowers.

3. Change holders in a six-glower lamp if two glowers are out; in a four-, three-, or two-glower lamp if one glower is out; and in a one-glower lamp if the glower does not light.

4. After replacing the holder, see that all glowers light up; if any does not, the corresponding ballast is burnt out and must be renewed.

5. All defective holders should be returned to the repair bench. The shades and glassware should be cleaned as often as necessary—at least once a month.

TUBE LIGHTING

39. For two centuries or more it has been known that an electric discharge through a tube of rarefied gas, or vapor, causes the gas to become luminous. Within recent years, much experimenting has been done, with a view of developing a practical illuminant by using a tube of incandescent gas. It has been found that the luminous efficiency of a vacuum tube is 25 or 30 per cent.—many times better than the best arc or incandescent lamps. The prediction is freely made that further investigation will enable the production of a vacuum-tube light far more efficient than anything yet produced.

When light is radiated from a point, the intensity of the light striking an object at a distance from the source of light varies inversely as the square of the distance; hence, in order that objects at a considerable distance may be well illuminated, the source of light must be dazzlingly bright. When the source of light is extended over a considerable space, as in a tube of light, the law of inverse squares does not hold true; the light falling on an object at a distance from the source is greater than given by this law. Moreover, from such a distributed source, light is given off in all directions

perpendicular to a considerable length of tube, and sharply defined lights and shadows are avoided. This quality adapts tube lighting to rooms where there are many obstructions to the distribution of light from concentrated sources, as in rooms where much machinery is installed.

Two principal types of tube lights have thus far come into practical use: the *mercury-vapor lamp* in which a column of mercury vapor is heated to incandescence by the passage of a current of electricity through it, and the *Moore electric light* in which the incandescent body is a tube of rarefied gas consisting almost wholly of air. Far less heat is required to raise to incandescence the temperature of a column of rarefied vapor or air than a solid, such as used in incandescent and arc lamps; this accounts for the higher efficiency of the vacuum-tube lamp.

MERCURY-VAPOR LAMPS

40. The **mercury-vapor tube lamp** as used in the United States was invented and developed by Peter Cooper Hewitt; hence, it is commonly known as the **Cooper Hewitt lamp.** The standard types of this lamp consist essentially of a clear glass tube 1 inch in diameter, with a light-giving portion from 17½ to 45 inches long. In each end of the tube is sealed a platinum wire that terminates in an iron or mercury electrode, very similar to the electrodes of the Cooper Hewitt mercury-vapor converter; in fact, the idea of using the mercury arc to convert alternating current to direct current was conceived while experimenting with mercury-vapor lamps.

DESCRIPTION

41. Type H Lamp.—There are several types of mercury-vapor lamps; types *H*, *K*, and *P* are for direct current, and type *C* is for alternating current. The type *P* lamp is described at the end of this Section.

Fig. 18 shows a **type H lamp** complete with the canopy containing the adjusting and regulating devices; *a* is the holder without the reflector, which is normally supported

between the holder and the lamp tube *b*. The holder is hinged at its middle point *c*, and is provided with a suitable stop, so that when in operation the lamp remains in an inclined position. The anode *d* is a piece of iron, and the cathode is mercury contained in the blackened bulb *e*. The chain *f* serves to pull down, or tilt, the lamp when starting it.

Two type H lamps in series, with tubes $17\frac{1}{2}$ inches long, are used on circuits where the voltage is from 98 to 106, and

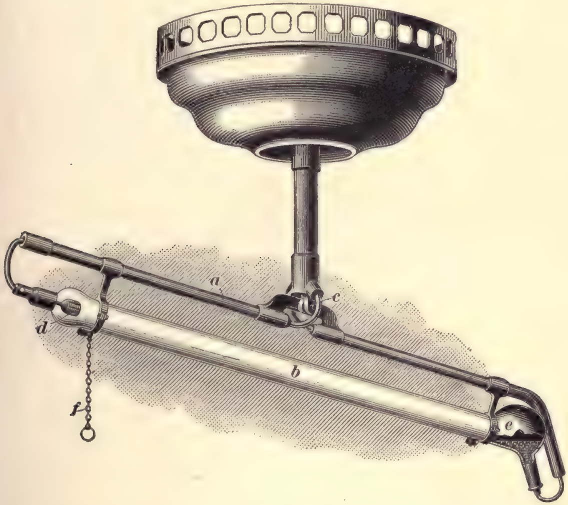


FIG. 18

two $20\frac{3}{4}$-inch tubes are used on from 106- to 122-volt circuits. At 110 volts, the two lamps consume 3.5 amperes, or 385 watts, and give off 300 spherical candlepower each, or a total of 600 candlepower, thus making the specific consumption .64 watt per candlepower. A lamp of this kind, with a special resistance in series, can be used on from 98- to 122-volt circuits, and four lamps can be used in series on from 196- to 244-volt circuits.

42. Type K Lamp.—The **type K lamp** has the same general appearance as the type H, but the light-giving portion of the tube is 45 inches long. Type K lamp can be used singly on from 98- to 122-volt circuits, or two in series where the voltage is from 196 to 244. With one of the two lamps shunted by a special resistance, the other can be used on from 196- to 244-volt circuits. Each lamp consumes 385 watts ($3\frac{1}{2}$ amperes at 110 volts) and gives off 700 candlepower, making the specific consumption .55 watt per candlepower.

43. Type C Lamp.—Fig. 19 shows a **type C lamp** for use with single-phase alternating current only. The general appearance is very similar to that of the type H or type K

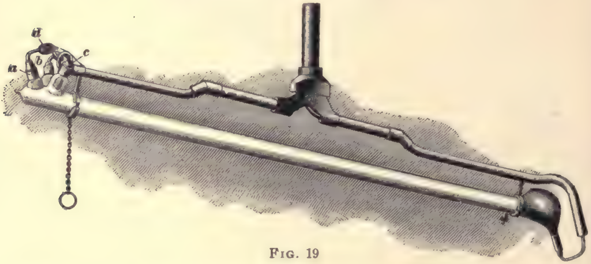


Fig. 19

lamp, except that the type C lamp combines the features of the direct-current lamps and the mercury-vapor converter, and hence has three anodes, one *a* for starting and two *b* and *c* for operating the lamp. The complete lamp has a canopy not shown in the figure. A resistance *d* in series with the anode *a* prevents the flow of an excessive starting current. The length of the light-giving portion of the tube is 28 inches. With each lamp is supplied an autotransformer, making the lamp suitable for use singly on from 98- to 244-volt circuits. The lamp consumes $3\frac{1}{2}$ amperes on 110 volts and has a power factor of $71\frac{1}{2}$ per cent., making the actual consumption $3\frac{1}{2} \times 110 \times .715 = 275$ watts. The output is 425 spherical candlepower; hence, the specific consumption is .64 watt per candlepower.

44. Cooper Hewitt Lamp Reflectors.—Fig. 20 shows the different forms of **reflectors** used with mercury-vapor lamps. The flat type is supplied where a medium distribution of light is desired; the curved type is used for concen-

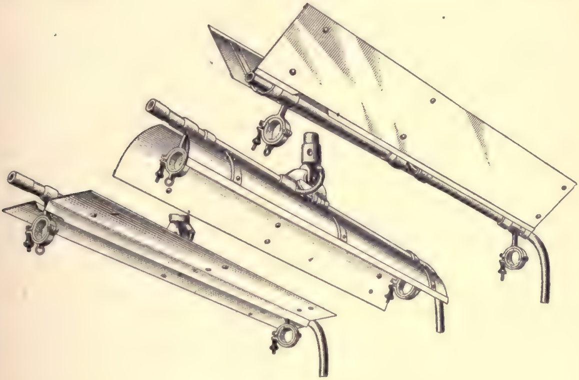


FIG. 20

trating most of the light immediately under the lamp; and the adjustable type permits almost any desired distribution to be obtained. With light-colored walls and ceiling, best results are obtained without the use of reflectors.

CONNECTIONS

45. Fig. 21 shows a diagram of the connections of two type H lamps in series, on a 110-volt circuit. A ballast *a*, very much like that used in the Nernst lamps, tends to keep the current nearly constant through considerable variations of the voltage. A resistance *b* in series with both lamps helps to steady the current and prevents it from being excessive at starting. Inductance, or reactance, coils *c*, *c'*, also in series with the lamps, prevent sudden fluctuations of current and act as magnets to hold the automatic switches *d d'* open while both lamps are in operation. If one lamp is out of

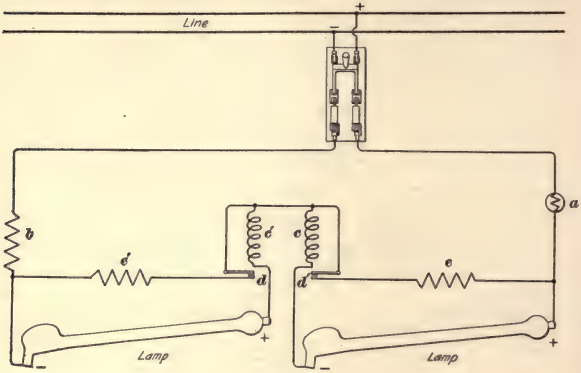

Line
+
−
a
b
c'
c
d'
d
d
e'
e
Lamp
+
−
Lamp
+
−

FIG. 21

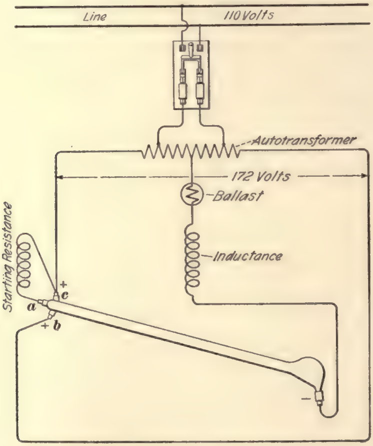

Line
110 Volts
Autotransformer
172 Volts
Ballast
Inductance
Starting Resistance
+
c
a
+ b
−

FIG. 22

service for any reason, its inductance coil carries no current and its automatic switch remains closed, thus allowing the current from the other lamp to pass around the idle one through a special shunt resistance *e* or *e'*. It is thus possible to burn either lamp singly if desired. Two pair of type H lamps in series, each pair connected as shown in Fig. 21, can be used across from 196 to 244 volts. The connections for two type K lamps in series are very nearly the same as for two type H lamps. When one lamp of either type is connected for use alone, the automatic switch is omitted, but a resistance and an inductance are used in series with the lamp.

46. Fig. 22 shows a diagram of the connections of a type C lamp. The connections are the same as those of the single-phase mercury-vapor converter, except that in the lamp connections a ballast is used in the line from the cathode to the autotransformer. The autotransformer shown is suitable for use on 110 volts; a different one is used for 220 volts, the transformation ratio being such that the pressure across the lamp terminals is 172 volts in each case.

47. The adjusting and regulating devices for each lamp are arranged in a compact group called the **auxiliary,** which is usually placed in the large canopy above the lamp. Fig. 23 shows the inner parts of the type C lamp, the arrangement of which is typical of all. A plate *a* is fastened to the ceiling, a shield *b* of sheet iron and asbestos comes next, and the plate *c* to which the resistances, inductances, etc. of the auxiliary are attached is then fastened to the ceiling plate. The asbestos shield protects the ceiling from heat that might be generated in the auxiliary. The plate *c* carries a crowfoot *d*, into which the suspension bar *e* is screwed. The parts are shown suspended in the order in which they go together. When assembled, the canopy covers all the parts, as shown in Fig. 18. The position of the lamp is indicated in Fig. 23 by dotted lines, and the holder, reflector, clamps, etc. are shown.

When the ceiling is fireproof, the plate is attached to it by means of expansion bolts or other suitable devices; when the ceiling plate is attached to an outlet box, an insulating joint is used. The auxiliary can be screwed direct to wooden

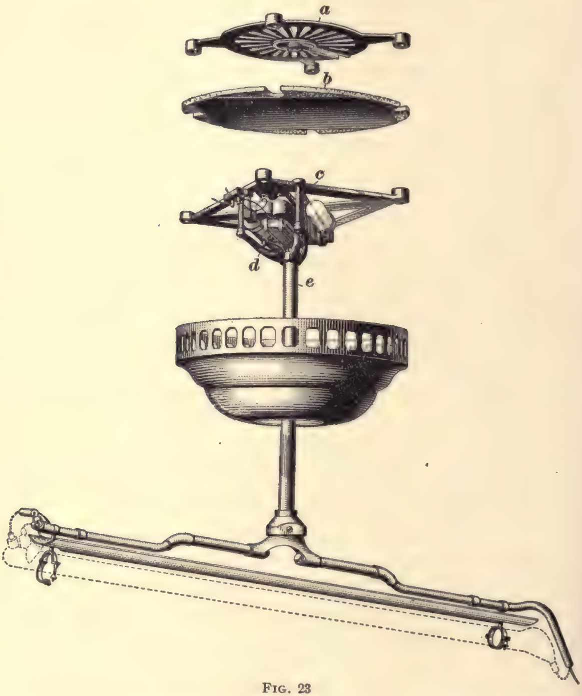


Fig. 23

ceilings without the use of a plate, but it must be spaced $\frac{3}{4}$ inch from the ceiling by porcelain insulators, and the asbestos shield must not be omitted.

48. In Fig. 24 is shown a diagram illustrating the relative location of the various parts of two type H lamps. The

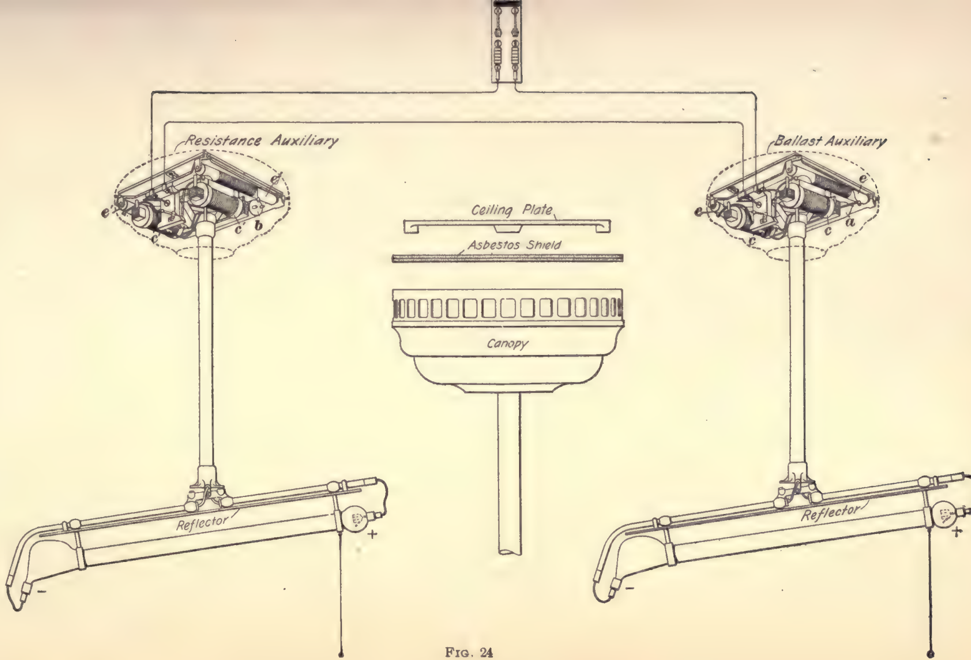

Resistance Auxiliary
Ballast Auxiliary
Ceiling Plate
Asbestos Shield
Canopy
Reflector
Reflector

FIG. 24

auxiliary of one lamp contains the ballast *a*, and that of the other lamp contains the series-resistance *b* (see also Fig. 21); hence the names, ballast auxiliary and resistance auxiliary. Each auxiliary is provided with inductances c, c' and shunt resistances e, e', each in two parts; also a canopy, shield, and plate like the ones shown.

In assembling a pair of lamps, the canopy is first slid down over the suspension bar, which is then screwed tightly into its auxiliary. The two wires protruding from the top of the suspension bar are provided with terminal plugs, which fit into holes in the binding posts to which they should be connected, the posts being marked + and −. In all cases, the wire from the positive end of the lamp should be connected to the positive post, and the wire from the negative end to the negative post. A wire connection is made between the posts marked *B* on the ballast auxiliary and the post marked *R* on the resistance auxiliary, and the wires from the supply circuit are connected to the remaining posts, the positive to the ballast auxiliary and the negative to the resistance auxiliary.

The clamps holding the tubes should be left loose enough so that the tubes can be turned easily; also, the tubes should remain tilted, as shown in Figs. 18 to 24, so that the mercury will remain in the cathodes. It may be necessary in some cases to add a small weight to the cathode end to keep it in the lower position.

OPERATION

49. Before starting mercury-vapor lamps, it should be ascertained that all connections have been properly made. The polarity of the direct-current lamps should be verified with considerable care, as an attempt to start with the current flowing in the wrong direction will melt the end of the negative leading-in wire, break the glass, and thus ruin the lamp. In starting, close the main switch, pull down on the chain until all the mercury has run from the cathode to the anode end of the tube; and then allow the tube to fall back slowly to its normal position. When the mercury forms

a continuous stream between the electrodes, about double the normal running current flows through the lamp, and when the stream is broken, the tube at once becomes filled with a glow of light.

In some types of lamps, a magnet is so arranged that when the main switch is closed the lamp is automatically tilted. In all cases, the lamp, after being tilted, should promptly return to the normal position with the cathode end down; it should not be permitted to burn long in any other position. The overload at starting will injure the lamp if maintained long; that is, if the tube is held for some time in a horizontal position.

COMPARISON WITH OTHER LIGHT SOURCES

50. The principal advantages claimed for the Cooper Hewitt mercury-vapor lamp are its high operating economy, uniform distribution of light, and the ease of the light to work by. The chief disadvantage is the absence of red rays, which gives the light a ghastly greenish appearance and renders it useless where colors must be distinguished. In such light, red appears as dark purple, and any color of which red is an element is distorted.

In economy, the mercury-vapor lamps are much superior to any of the older forms of electric lights, as may be seen by comparing the energy consumption per candlepower of the mercury lamp with that of the incandescent and arc lamps, as already given. Less than 1 per cent. of the energy supplied to carbon-filament incandescent lamps is converted into light, all the remainder being converted into heat. Of the energy supplied to mercury-vapor lamps, about 20 per cent. becomes light and 80 per cent. heat. The mercury-vapor lamps are therefore comparatively cool and heat up the surrounding air much less than either incandescent or arc lamps giving the same light output.

51. The superior distribution obtainable with tube lighting is illustrated, in the case of the mercury-vapor lamps, by the lighting of presses in some of the large printing

establishments. To light such machinery with ordinary incandescent lamps requires the installation of many lamps inside the presses. For example, it was estimated that forty incandescent lamps would be required to illuminate each of four large presses in one office, and that it would be necessary to drill 450 holes in the framework of each press to install the necessary conduits. In addition to these lamps, ten enclosed-arc lamps would have been needed to give the room sufficient general illumination. Instead of adopting this scheme of lighting, twenty-six type H mercury-vapor lamps were installed; the presses are thoroughly well lighted and no holes in the frames were necessary. The incandescent and arc lamps would have required about 15 kilowatts of energy; the mercury lamps require about 5.5 kilowatts.

52. The light from the mercury-vapor lamp is easy on the eyes for several reasons: it is very steady, there being no flicker or perceptible variation whatever; the source is not so dazzling as to cause the pupils of the eyes to contract and thus shut out the reflected light from the objects it is desired to see, such as printed pages, drawings, machinery, boxes or bales of goods, or whatever it may be; the prevailing color of the light is green, which is best suited to the eyes, while the trying red rays are entirely absent; and as the source is distributed, there are few sharp contrasts between lights and shadows to tire the eyes in making continuous adjustments.

For factories, warehouses, depots, offices, drafting rooms, press rooms, reading rooms, and all places where color distortion is not objectionable, this form of light is very desirable. Many attempts have been made to use a substance for the cathode that will give off all the colors in about the proportion that they exist in sunlight, but nothing so desirable as mercury has yet been found.

MOORE LIGHTING TUBES

53. The **Moore electric light** is a system of artificial lighting in which the source of light is the rarefied, non-metallic, gaseous contents of long glass tubes, made luminous by the passage of an electric current. The Moore tube can be made in many sizes and shapes, but usually it consists of a clear glass tube $1\frac{3}{4}$ inches in diameter and whatever length is desired up to 200 feet. The tube is usually placed near the ceiling, the two ends entering a small steel terminal box placed in any convenient location.

54. Theory of the Moore Light.—To explain the theory of the Moore lamp, reference is made to Fig. 25, which shows the appearance of a series of discharges of electricity in air at atmospheric pressure. If the difference of potential between two points or terminals in open air is gradually raised, sparks will finally jump from the positive terminal across the intervening air space to the negative terminal, as shown. The path of the discharge will not be

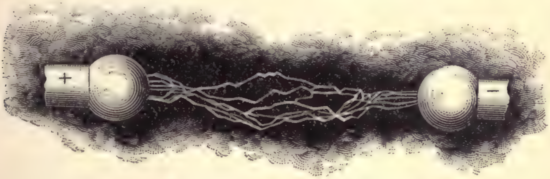


FIG. 25

a straight line, for the electricity will seek the path of least resistance, which includes particles of dust that may be floating in the air. The same tendency is seen when a lightning discharge passes in a zigzag path from cloud to cloud or from a cloud to the earth.

If the two terminals are sealed in a glass tube and the air is gradually exhausted from the tube, a condition will soon be reached where the discharges, instead of following zigzag paths, as in open air, will become straight and continuous and will fill the tube with a glow of light. The electromotive

force required to cause the discharge changes as the degree of exhaustion, or the pressure, of the air in the tube changes. At first the necessary electromotive force decreases rapidly as the pressure decreases, but a condition is soon reached where the electromotive force is a minimum, and the tube is completely filled with a bright glow. If the air pressure is further reduced, the electromotive force will have to be increased and the light will be less brilliant. For best results as a light source, therefore, the vacuum in the tube must be maintained at a definite pressure.

The color of the light emitted when the tube contains

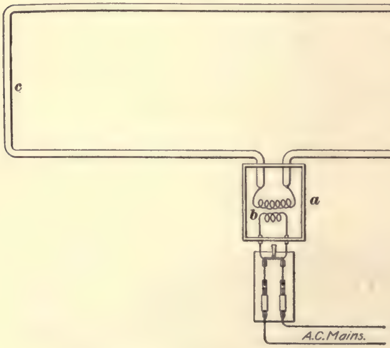


FIG. 26

only rarefied air is a rosy pink, but by introducing a small quantity of a suitable gas, the color can be made any shade desired; the light, in fact, can be made pure white. The coloring gas soon becomes exhausted and must be frequently renewed.

55. Moore Tube Connections.—Fig. 26 shows the very simple connections of a Moore tube. The pressures required are usually higher than are practicable with direct current. Low-potential alternating current, such as is permitted by the Fire Underwriters' rules to be brought inside buildings for incandescent lighting, is led through fuses

and a switch into a fireproof and danger-proof box *a* and through the primary coil of a potential-raising transformer *b*. The secondary coil of the transformer terminates in carbon electrodes in the ends of the tube *c c*, inside the box. No wiring is necessary, except to bring the low-potential mains to the box, thus making the system very safe. Fig. 27 illustrates an interior view of one of these terminal boxes, which has been in successful commerical use for several years.

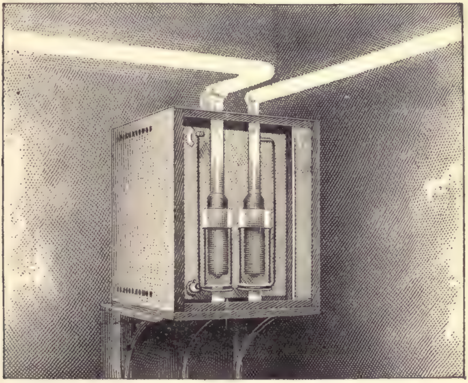


FIG. 27

When the main low-potential switch is closed, the tube lights up immediately with a glow that can easily be regulated, so that it will give any desired intensity from 2 to 25 or 30 candlepower per linear foot of tubing. The actual current passing through the tube, assuming that it is radiating 15 candlepower per foot, is about $\frac{1}{3}$ ampere, varying somewhat with the color of the light desired.

56. Vacuum Regulator.—The passage of electric current through the tube in a Moore light soon burns out the small quantity of air or other gas needed to maintain the conductivity, and it is necessary to admit a minute quantity to the tube at intervals, or the current will soon cease to flow.

The **vacuum regulator,** shown in section in Fig. 28, is a device for automatically feeding air to the tube. The vacuum is maintained at a little above the point of least resistance; therefore, as the degree of exhaustion increases, the resistance decreases and the current increases.

The regulator consists of a valve operated by an electromagnet connected in series with the primary or the secondary of the transformer feeding the tube. A porous carbon plug *a* is sealed into the top of a glass tube *b*, around which is an annular space filled with mercury *c*. Into the annular space extends a movable tube *d*, the other end of which is attached to the core *e* of the magnet. As the excitation of the magnet changes, the core moves up or down, thus moving tube *d* up or down in the mercury. The surface of the mercury is thus lowered or raised.

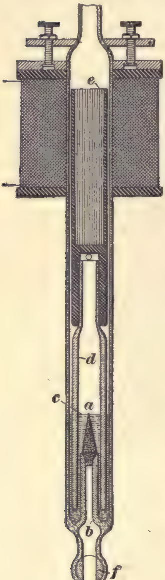


Fig. 28

Above the surface of the mercury is a space filled with air or other gas, and when the tip of the carbon plug is exposed an extremely small quantity of the gas filters through the plug and passes into the lighting tube. By means of a stop-cock *f*, the regulator can be shut off from the lighting tube. If the tube is fed with pure air, the light will be a rosy pink; if the air supply is first passed through phosphorus, the oxygen is withdrawn, leaving only nitrogen to enter the tube, and the light will then be yellow, which is the most economical color; or, the tube can be fed with carbon-dioxide gas, generated by the contact of a piece of marble with a little hydrochloric acid, in which case the light will be pure white.

In operation, the valve acts about once a minute; the current gradually rises until the valve acts, then gradually falls, as the newly admitted gas diffuses through the tube, until

the degree of exhaustion begins to increase again, thus working between fixed limits. No variation in the brilliancy of the tube can be detected, and in spite of the continual

FIG. 29

admission of new material, no change can be noticed except a deposit near the electrodes, and this is very slight, even after long-continued use.

57. Applications of the Moore Tubes.—Fig. 29 shows the Moore tube light in the main-corridor entrance to Madison Square Garden, New York City. This tube is 100 feet long and is arranged in the form of a rectangle hung near the ceiling.

In Fig. 30 is shown an artificial skylight for photographic purposes, made by bending a Moore tube back and forth over the surface of a window-like box. This skylight is located in one of the large New York City photograph galleries, and after 2,500 hours' service, extending over

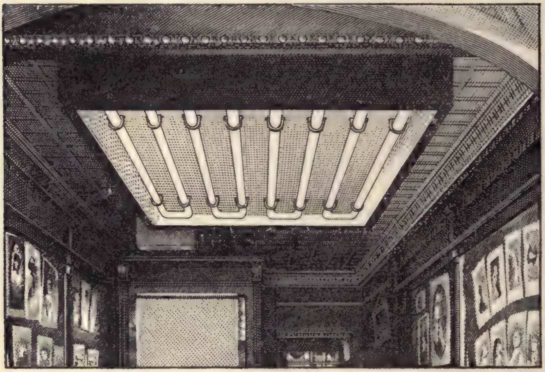


Fig. 30

$1\frac{1}{2}$ years, it showed no change in its conditions or its light output, and indicates indefinite life. A modified form of this device, in which the box carrying the tube is mounted in a frame so that it can be adjusted to any angle, is used by many photographers as an artificial photographic window.

Fig. 31 illustrates an adaptation of a Moore tube to electric advertising, to which it readily lends itself, as it can be bent into any form desired. This form of light is also applicable to large areas where uniform light is desired, such as stores, offices, restaurants, public halls, churches, theaters, libraries, art galleries, subways, and even to street lighting.

The longer tubes, such as shown in Fig. 29, are sent out from the factory in sections 8 feet 6 inches long, and are united into one continuous air-tight tube, being exhausted when mounted in their permanent location. This makes the system somewhat troublesome to install, but the expense is less than that of a first-class system of incandescent lighting, including wiring, fixtures, and shades.

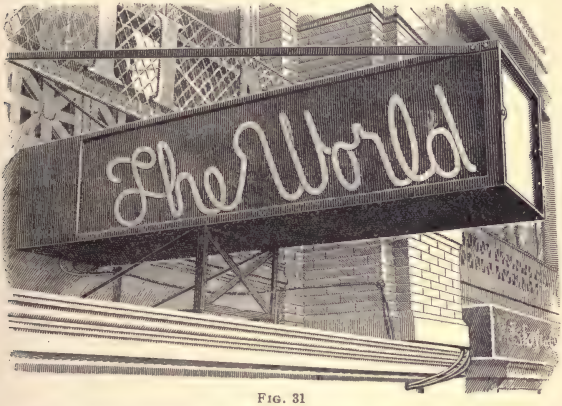


FIG. 31

58. Characteristics of Moore Tubes.—Moore lighting tubes require alternating current at any of the frequencies ordinarily used for incandescent lighting. If the supply current is direct, a motor-generator, dynamotor, or rotary converter must be used to transform it into alternating current. Direct current, however, could be used in the tube, provided sufficient voltage could be obtained. The voltage required depends on the length of the tube and on the brilliancy at which it is operating. Curve *a*, Fig. 32, shows the volts at the tube terminals when operating at 12 hefners per foot. A tube 100 feet long requires about 7,150 volts, or 71.5 volts per foot; a tube 150 feet long, about 9,750 volts, or 65 volts per foot; and a tube 200 feet long, 12,250 volts, or 61.3 volts per foot.

Curve *b*, Fig. 32, shows the low tension, or primary, amperes at 220 volts for different lengths of tube operating at 12 hefners per foot, and curve *c* shows the total energy in kilowatts. Since the supply voltage remains constant and the energy supply increases with the length of tube, the primary amperes must increase.

59. The **brilliancy** of the tube in the Moore light increases slightly during the first 100 hours of service, and after that remains fairly constant with constant voltage. The

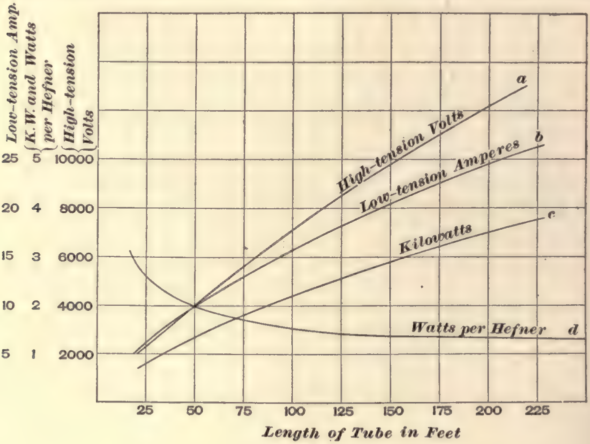


FIG. 32

light output increases about in direct proportion to the increase in voltage, and the tube is not injured by a considerable variation of voltage. The greatest brilliancy at which the tube can be made to burn (about 30 candlepower per linear foot) is not great enough to strain the eyes when looking directly at it.

The **efficiency** of the tube also increases during the first 100 hours of service, but afterwards there is no apparent change during the life of the lamp, provided the voltage remains constant. Increased voltage causes not only increased

brilliancy, but also increased efficiency. The efficiency of long tubes is greater than that of short ones. Curve *d*, Fig. 32, shows the relation existing between the length of a tube and its consumption of power at 12 hefners per foot. A tube 50 feet long consumes about 2 watts per hefner unit; a tube 100 feet long, 1.6 watts per unit; a tube 150 feet long, 1.35 watts per unit; etc. Recent tests made on a 179-foot tube that had been in use 1,000 hours showed a power consumption of 1.35 watts per hefner, at a brilliancy of 13 hefners per foot of tube. This tube was giving an orange-tinted light; when producing white light, the efficiency is lower. The power consumptions here given include that of the transforming device.

Among the objections to the Moore tube are the fact that it can be used efficiently only in large units and its low power factor—60 to 75 per cent. In many installations, the first objection is not serious, since the demand for large units, especially those having a distributed light source, is greater than that for small ones; the second may, perhaps, be largely removed with further developments.

FLAMING-ARC LAMPS

60. Up to 1894, the only arc lamps used in the United States were of the open-arc type. During the succeeding 10 years enclosed-arc lamps came into general use and gradually, with the exception of a few isolated cases, displaced open-arc lamps. Many varieties of enclosed-arc lamps are in use, most of them differing from one another only in mechanical details. There are differences in the methods of making up magnet coils and resistances, of insulating the electric circuits, adjusting and regulating the arc, enclosing the arc, etc., but the general principles on which nearly all enclosed-arc lamps operate are practically the same.

The chief reason for displacing the old-style open-arc lamps was the superior steadiness and quality of the light furnished by the enclosed-arc lamps, though the decreased cost of repairs and maintenance of the newer lamps was an

important consideration, especially in countries where labor costs are high.

61. Theory of Flaming-Arc Lamps.—All attempts to operate the old-style open-arc lamps with an arc longer than about $\frac{1}{8}$ inch resulted in a waste of energy. The additional power required to force the current through the longer arc was expended in a stream of hot gases, with but little increased light and greatly increased flaring and unsteadiness. The idea of inserting in the stream of hot gas a substance that would be heated to incandescence, and that would at the same time so increase the conductivity of the gas that the arc would remain steady, is an old one, but only within recent years has it been made practicable.

It has been found that if the carbons are impregnated with suitable mineral salts, the heat of the arc will vaporize the salts and heat the vapor to incandescence. The electrodes can then be drawn farther apart, producing a luminous arc from $\frac{5}{8}$ to $2\frac{1}{2}$ inches long. The color of the light from such an arc can be controlled to a considerable extent by the selection of the salts with which the carbons are impregnated. The salts most commonly used are those of calcium and magnesium. Lamps using such carbons and producing such arcs are usually called **flaming-arc lamps**; a more nearly correct designation, also sometimes used, is **luminous-arc lamps.**

When the carbons burn, the salts are converted into vapor, which not only becomes incandescent, thus making the arc a brilliant flame of light, but also affords a path of comparatively low resistance between the electrodes, so that the arc is much more steady than with pure carbons. The burning is accompanied by the production of noxious fumes, a considerable quantity of ashes, and particles of slag, or scoria. The fumes render such arcs somewhat objectionable for indoor use, except in the small sizes, and also prevent enclosing the arc. The ashes are deposited largely on parts of the lamp immediately above the arc, and being white, assist in reflecting the light downwards.

62. Description of Flaming-Arc Lamp.—If both carbons are impregnated and are arranged coaxially, that is, with the positive carbon above the negative, as in ordinary arc lamps, the scoria forms on the end of the lower carbon as a hard bead, which hinders the flow of current. To prevent this, one inventor has placed almost all the impregnating salts in the positive carbon, which is made the lower electrode in the lamp; the scoria then drops harmlessly away from the electrodes. The arc in such lamps is drawn to about $\frac{5}{8}$ inch and has the appearance shown in Fig. 33.

FIG. 33

63. In most flaming-arc lamps, the carbons are arranged side by side and are slightly inclined so that the lower ends approach each other at an acute angle, as in Fig. 34. All scoria then drops away from the carbons as soon as formed. In direct-current lamps, the positive carbon is slightly larger than the negative, so that both burn away at nearly the same rate; in alternating-current lamps, both carbons are the same size.

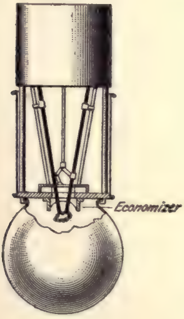


FIG. 34

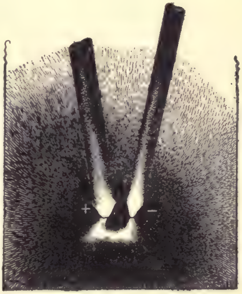


FIG. 35

The arc assumes the form shown in Fig. 35; its natural tendency is to pass across the shortest space between the electrodes, but it is prevented from doing so and is made to bow downwards from the carbon tips by magnets, which cause lines of force to pass across the path of the arc. The arc is thus forced in the same direction as would be a conductor carrying a current through the same field in the direction the current is flowing through the arc. By varying the strength of the magnetic field, the arc can be made to assume the form desired.

64. In the ordinary arc lamp, a large part of the light comes from the incandescent carbon tips, especially from the crater in the positive carbon. If the carbons are arranged coaxially, much of the light from the carbon tips is cut off by the lower carbon; if both carbons feed downwards, as in Fig. 35, there is nothing to interfere with the downward passage of all the light from both carbon tips, as well as that from the flame. About three-fourths of the light from a flaming-arc lamp comes from the flame itself; the remainder, coming from the incandescent carbon tips, contains an excess of violet rays, which improve the general quality of the light.

65. If permitted to enter the top of the lamp freely, the fumes and ashes from the impregnated carbons would be injurious to the mechanism. Moreover, in order to prevent too rapid consumption of the carbons, it is necessary to shield the arc as much as possible from air-currents. An **economizer,** that is, a chamber made of a material not easily affected by heat (see Fig. 34), surrounds as much of the arc as is necessary to shield it from air-currents, and affords a surface on which most of the mineral vapor is condensed.

EXCELLO FLAMING-ARC LAMP

66. Excello Direct-Current Lamp.—All flaming-arc lamps have many points of resemblance. Most of those first developed are made in Europe and have somewhat complicated regulating mechanism. Fig. 36 shows the principal electrical connections and mechanical details of the

Mathieson direct-current lamp sold in the United States under the trade name **Excello.** A shunt magnet *a* and a series magnet *b* are arranged at right angles to each other, and between them is an armature *c* pivoted at *d* and having arms *e* and *f*. When current is switched on to the lamp, the shunt magnet *a* is excited and armature *c* moves toward it, lifting arm *f* against the retarding influence of the dash-pot *g*. Attached to arm *f* is a rod *h*, the lower end of which is fastened to a slider *i*. When the rod is raised, the slider, through which the negative carbon passes, is drawn horizontally toward the positive carbon and the carbon tips are brought together, closing a circuit between the two lamp terminals through magnet *b* and the carbons. A momentary starting current 40 per cent. in excess of normal value causes the series magnet *b* to overpower magnet *a*,

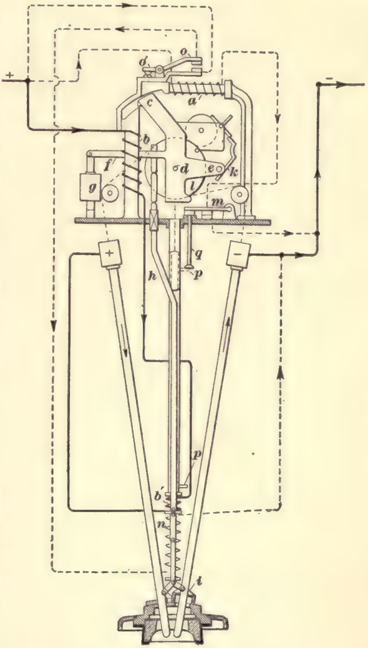


FIG. 36

and armature *c* is drawn back, the rod *h* lowered, and the slider *i* shifted outwards in a horizontal plane, thus separating the carbons and starting the arc. The current immediately drops to normal value. Armature *c* then remains floating between the series and shunt magnets.

As the ends of the carbons burn away and increase the length of the arc, the shunt magnet *a* becomes stronger until armature *c* is drawn over so far toward *a* that the arm *e* causes the detent *k* to release the feeding gear. This gear consists of wheels and pinions controlling the movements of drum *l*, around which is coiled the chains that support the carbons. When the carbons have fallen until the arc is again shortened to the proper length, armature *c* is drawn back automatically until the detent *k* arrests the movement of the gear. As the carbons fall, a detent, or tripping pin, attached to a third chain passing over the drum *l* gradually rises in the center tube, and when the carbons are consumed the pin has reached the position *p*, where it raises the stud *q* and opens the switch *m* in series with the shunt magnet *a*. Armature *c* is instantly drawn to its extreme position toward magnet *b*, forcing the slider *i* over so that the carbons are separated as far as possible, and the arc is broken. Coil b', in series with the arc, supplies the magnetism required to keep the arc blown down to the ends of the carbons. The higher voltage lamps have an additional blow-out coil *n* in series with a switch *o* across the circuit. While the lamp is operating, the shunt magnet *a* attracts the rear end o' of the switch, which is thereby held open; as soon as magnet *a* is cut out, switch *o* closes and coil *n* assists in blowing out the arc.

67. Excello Alternating-Current Lamp.—In Fig. 37 is shown the arrangement of the wiring and mechanism in an **alternating-current lamp.** A shunt magnet *a* is connected directly across the lamp terminals through the switch *m*, while a magnet *b* is connected in series with the blow-out coil b' and the arc, these connections being similar to those of the direct-current lamp. A copper disk *c* is arranged to rotate near the poles of magnets *a* and *b*. Alternating magnetism in the poles sets up eddy currents in the disk, and the reaction between these currents and the magnetism causes the disk to rotate, the direction of rotation depending on the relative strength of the magnets. When the

lamp is ready for operation, the carbon ends are in contact, and when the lamp is switched on to the circuit—the resistance through coils b, b' and the carbons being low —a considerable current flows, and series magnet b is strongly excited. This causes wheel c to rotate in a direction to wind the chains on the drum l and draw the carbons apart, thus striking the arc. The voltage across the arc soon causes the shunt magnet a to become excited enough to balance the effect of the series magnet b on the rotating disk, which therefore comes to rest with the proper length of arc. The two magnets act differentially on the disk while the lamp is operating and automatically keep the arc adjusted. When the carbons are burned out, the pin on piston p lifts the stud q and opens the switch m in the shunt circuit; the series magnet at once causes the carbons to be separated so far that the arc is broken.

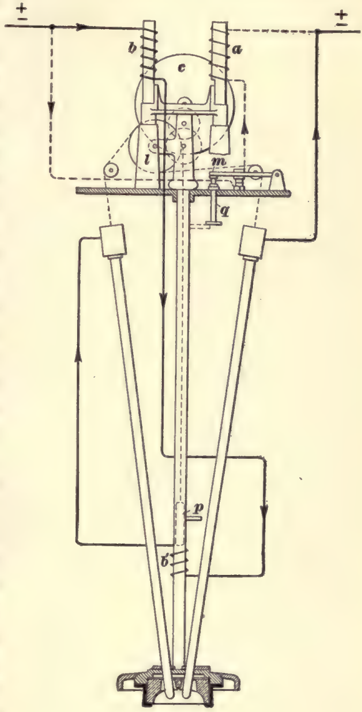


Fig. 37

68. Excello Lamp Economizer.—Fig. 38 (a) shows a view of the economizer a and the carbon tips while the arc

is burning; b is a blow-out coil, consisting of a few series-turns to hold the arc down on the carbon tips and a number of auxiliary shunt turns that are used only to help blow out the arc when the carbons are consumed. Rods c, c are a part of the framework of the lamp, and d, d are the carbons. Fig. 38 (b) shows the position of the carbon ends when they have been automatically separated and the arc disrupted.

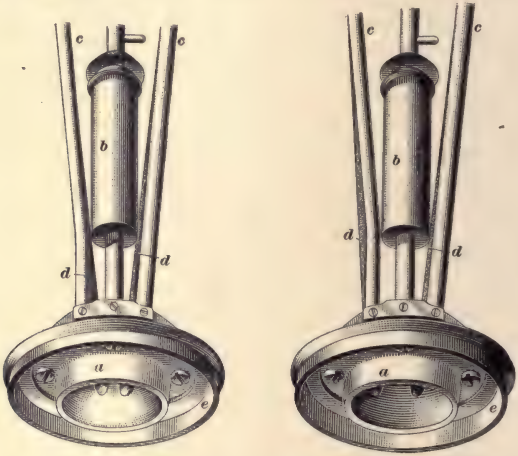


Fig. 38

Suitable ventilating holes are provided around the economizer for the escape of gases, and the pan underneath the globe (not shown) contains holes to admit the air needed by the arc. The globe surrounds the arc and fits tightly inside the rim e. All the lamp mechanism is housed as completely as possible, to protect it not only from the weather, in case of outdoor lamps, but also from the fumes of the lamp.

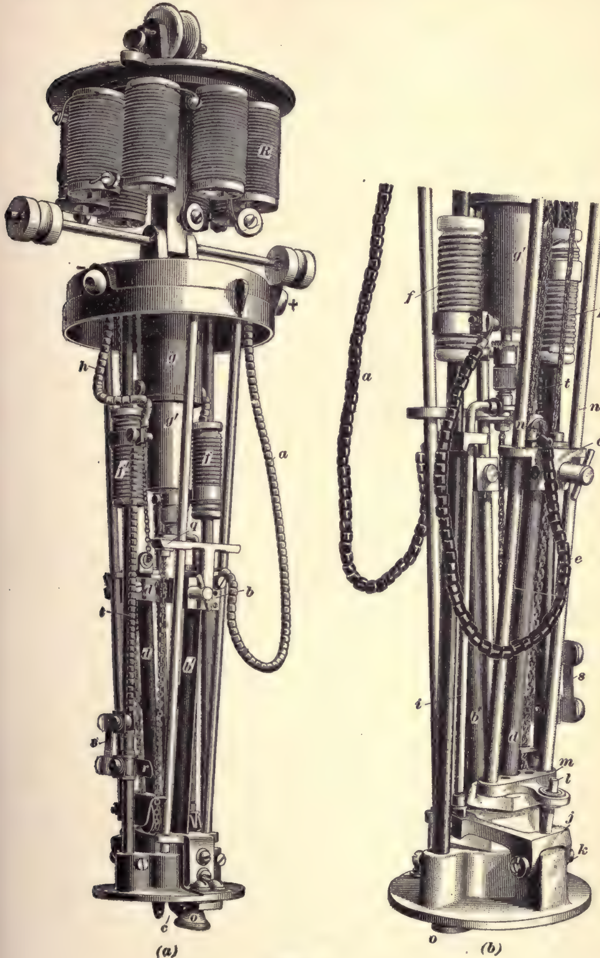


FIG. 39

THE BECK LAMP

69. Fig. 39 (*a*) and (*b*) are front and rear views of the interior of a **Beck direct-current flaming-arc lamp,** with resistance on spools R such that the lamp can be operated singly on a 110-volt circuit. Without the resistance, this lamp is suitable for use on from 55 to 65 volts, two in series on from 110 to 120 volts, or four in series on from 220 to 240 volts. The resistance may be connected in either the positive or the negative line. Assuming that it is in the positive line, the current passes through the resistance and enters the positive terminal of the lamp, through which it takes the following path: positive cable a, carbon holder b, and carbon b'–arc c–negative carbon d, holder d', and cable e [shown only in (*b*)]–arc blow-out coil f–lifting magnet g–arc blow-out coil f'–cable h, to the negative terminal.

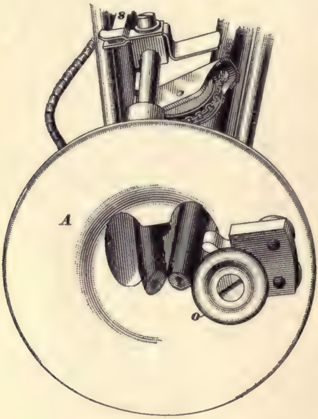


FIG. 40

Fig. 40 is a view of the bottom of the lamp, showing the economizer A and the carbon tips as they rest together when the lamp is ready for operation. When the current is switched on, the magnet g, Fig. 39 (*a*), lifts the rod i, Fig. 39 (*b*), which turns the casting j on the pivot k, causing the pin l to move the casting m and its attached porcelain piece, through which the negative carbon passes, away from the positive carbon, thus striking the arc. A dashpot g' steadies the movements. The rods n, n are so fastened in the top of the lamp as to allow them to swing outwards at the bottom. While the lamp is operating, some of the magnetism produced by the

blow-out coils *f*, *f* follows down the side rods to the bottom of the lamp, and enough of it crosses the space between the carbon tips to force the arc down, so that it forms a bow, or inverted arch, between the tips.

70. Running the whole length of one side of the positive carbon is a rib that rests on a cone-shaped metal wheel *o*, Figs. 39 and 40. This rib burns to a fine point where it rests on the wheel, gradually crumbles off, and allows the carbon to drop slowly. The two carbon holders are connected by a chain, as shown diagrammatically in Fig. 41. The chain is insulated from each holder and passes around two pulleys *p*, *p'*—one in the top of the lamp and one in the bottom. When the ribbed carbon drops, the chain moves over the pulleys and permits the other carbon to drop an equal amount, so that the two feed down together.

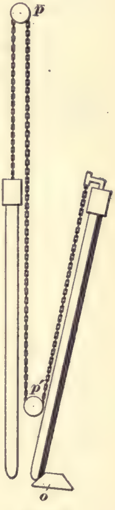


Fig. 41

When the carbons are burned as short as they can be without injuring the lamp, a projection on the positive holder pushes the negative holder to its extreme outward position, making the arc as long as possible, after which the projection *q*, Fig. 39 (*a*), on the positive holder touches the contact piece *r*, which is connected through the fuse *s* and cables *t* and *h* to the negative terminal of the lamp. This short-circuits the lamp, puts out the arc, and at the same time blows the fuse. As the carbons are held apart, the arc cannot start again.

A sheet-metal casing encloses the lamp mechanism, and a large translucent globe surrounds the arc and protects it from air-currents. The size and appearance of the completed lamp do not differ materially from those of ordinary arc lamps. The alternating-current lamps operate on the same general principles as the direct-current lamps, very few minor changes being necessary.

CHARACTERISTICS OF FLAMING-ARC LAMPS

71. Impregnated Carbons.—The **impregnated carbons** used in nearly all flaming-arc lamps consist of three zones, or layers: (1) An inner soft core made of a mixture of carbon and salts of calcium, magnesium, or whatever metal is required to give the desired color; (2) a layer of the same materials more firmly compressed; (3) an outer layer of firmly compressed pure carbon, giving mechanical strength to the whole. In some cases, in order to reduce the resistance, the carbons have a metallic core. Fig. 42

FIG. 42

shows a pair of carbons, such as used in the Excello lamps, broken in pieces to show the metallic core.

The impregnated carbons used in flaming-arc lamps are expensive and they last only from about 8 to 20 hours, according to their length and the quantity of current in the arc. If used for street lighting, it is necessary to trim most flaming-arc lamps about every day, as was done with the

TABLE III

COMPARATIVE LAMP TESTS

Comparisons	Flaming Arc	Enclosed Arc
Mean amperes	8	5.1
Mean volts at the arc	45	81
Mean watts at the arc	360	413
Mean spherical candlepower	1,020	232
Mean lower hemispherical candlepower	1,560	260
Watts per mean spherical candlepower	.353	1.78
Watts per mean hemispherical candlepower	.231	1.59

old-style open-arc lamps. The cost for maintenance is therefore high. Some lamps have been arranged with a magazine holding a number of carbons in such a way that as soon as one pair is exhausted another pair is automatically substituted.

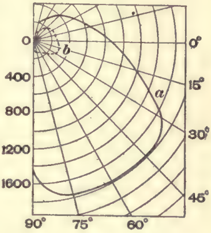


FIG. 43

72. Candlepower and Distribution.—The data given in Table III are from tests made by the Electrical Testing Laboratories, New York City, on a flaming-arc lamp (the Excello) and on a direct-current enclosed-arc lamp.

The distribution of light as determined by the tests just mentioned is illustrated graphically in Fig. 43. The arcs of circles represent the intensity of the light in candlepower,

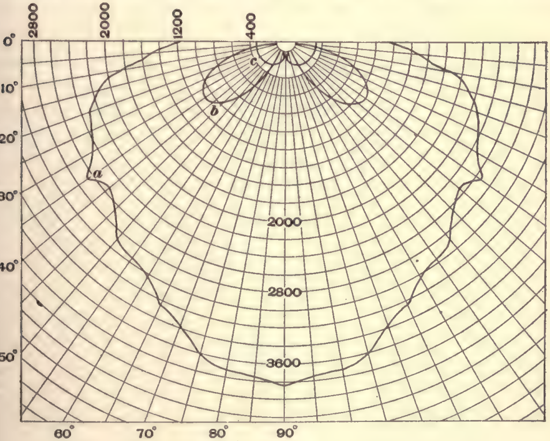


FIG. 44

as shown by the figures along the left-hand margin. The center *0* shows the position of the lamps, while the full-line curve *a* represents the light given off by the flaming arc,

and the dotted curve *b*, that given off by the enclosed arc. The two curves have the same general shape, showing that the light is distributed from both lamps in very much the same way; but the flaming arc gives off nearly six times as much light as the enclosed arc. The maximum light from the flaming arc is given off in the angular space between 30° and 75° below the horizontal, and decreases slightly directly under the lamp. The flaming-arc lamp had an opalescent globe, and the enclosed-arc lamp had an opalescent inner globe but no outer globe.

The distribution of light from a flaming-arc lamp with downward-feeding carbons and no globe is shown by curve *a*, Fig. 44. Curve *b* shows the distribution and the relative intensity of light from an old-style open-arc lamp, and curve *c* the corresponding quantities for an enclosed-arc lamp.

73. The effect of impregnating the carbons with different light-producing minerals is shown in Fig. 45. The same lamp with different sets of carbons was used for each curve, and the lamp consumed the same power in each case. The white light, curve *a*, was produced at an expenditure of 1.202 watts per spherical candlepower; the red light, curve *b*, at 1.03 watts; and the yellow light, curve *c*, at .716 watt. These curves were taken with an alternating-current lamp consuming 578 watts.

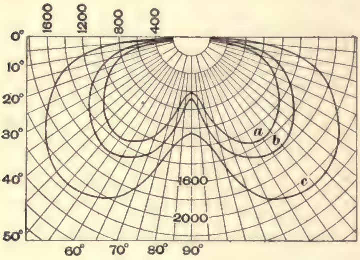


FIG. 45

CARBONE ARC LAMPS

74. The **Carbone arc lamp** is the result of an attempt to secure with pure carbons the advantages of downward-feeding inclined carbons and also freedom from interference with light reflection from the carbon tips. From 80 to 90 volts are used across the arc, which is forced down to the carbon tips by suitably arranged magnets. Fig. 46 shows the position of the electrodes *a* and the magnets *b*, *b* for steadying the arc. Most of the magnetism traverses the iron ring *c*, but holes *d*, *d* increase the *reluctance* of the ring, that is, its opposition to the passage of magnetism, and enough lines of force leak across from one side of the ring to the other to cause the arc to spread out and bow downwards in the form of a spherical segment. An economizer fits inside the iron ring *c* around the carbon tips.

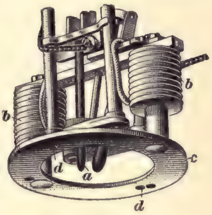


FIG. 46

Considerable advantage is obtained over the ordinary arc lamp, and although the efficiency is not so high as with impregnated carbons in the flaming-arc lamp, the Carbone lamp has the advantage of using very much cheaper carbons. Table IV gives comparative results in hemispherical candlepower.

TABLE IV

COMPARISON OF VARIOUS ARC LAMPS

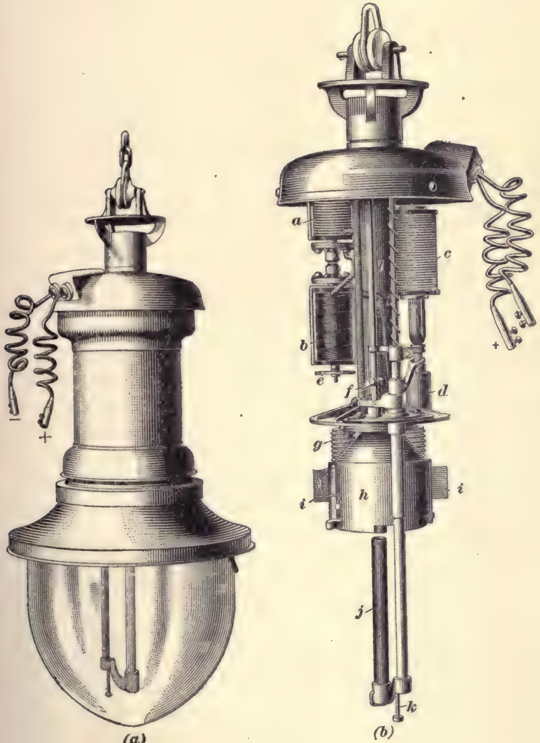
Type of Lamp	Candlepower per Ampere	Candlepower per Watt	Watts per Candlepower
Ordinary open arc	82	1.54	.65
Enclosed arc	55	0.77	1.3
Carbone arc	200	2.24	.445
Impregnated-carbon arc	259	5.78	.173

MAGNETITE LUMINOUS-ARC LAMP

75. In any electric arc, the material that supports the arc issues from the negative electrode as a high-velocity arc blast, which strikes the positive electrode and heats it. Unless the positive electrode is large enough to conduct this heat away, it may get hotter than the negative electrode, as is the case with ordinary arc lamps, in which the positive carbon is burned away nearly twice as fast as the negative carbon. The size of the positive electrode may be made such that it will wear away but very little; if too large, the material from the negative electrode will be deposited on it.

The **magnetite luminous-arc lamp** developed by the General Electric Company has a copper positive electrode large enough to be practically unaffected by the arc; also a negative electrode, made up by packing in thin iron tubes, 8 inches long by $\frac{5}{8}$ inch diameter, very finely divided *magnetite*, or black oxide of iron, in which are mixed small quantities of salts of chromium, titanium, etc. Pure magnetite does not give such high efficiency nor produce so steady an arc as that containing the other salts mentioned.

76. In Fig. 47 (*a*) is shown a luminous-arc lamp complete, and in (*b*), the interior with the globe and casings removed. At *a* is shown the series magnet; *b*, the shunt magnet; *c*, the starting magnets (one directly back of the other); *d*, the dashpot; *e*, the adjusting armature disk, for regulating the frequency of the automatic arc adjustments; *f*, an adjustable stop, for regulating the length of the arc; *g*, the starting resistance, of which there are several spools; *h*, an iron box, through a slot in which extends the positive electrode *i*—a copper bar; *j*, the negative electrode; *k*, the tripping rod; and *l*, a central tube, or chimney, for discharging the gases from the arc out of the top of the lamp. These lamps are used only with direct current, either in series on constant-current circuits or in multiple on constant-potential, 110- or 220-volt circuits.



(a) (b)

FIG. 47

77. Fig. 48 is a diagram of connections of a **constant-current luminous-arc lamp.** When the lamp is idle, the carbon blocks *m* are in contact, and when the current is switched on, it takes the path from the positive terminal through the starting resistance *g*–the carbon blocks *m*–and the starting magnets *c*, to the negative terminal. The starting magnets lift their armature *n*, thus raising the negative electrode *j* until it makes contact with the positive electrode *i*. The larger part of the current then takes the path from the positive terminal through the series magnet *a* and the electrodes to the negative terminal. The series magnet lifts its armature and separates the carbon blocks, thus cutting the shunt magnet *b* into circuit in series with the starting resistance and the starting magnets. When the carbon blocks separate, the addition of the resistance of the shunt magnet to the circuit through the starting magnets so weakens them that the armature *n* drops back instantly about $\frac{3}{16}$ inch and then slowly, as the dashpot retards the motion, until the arc is about $\frac{7}{8}$ inch long and has the appearance shown in Fig. 49. The flame is very brilliant and the light nearly white. This lamp has proven very successful for street illumination.

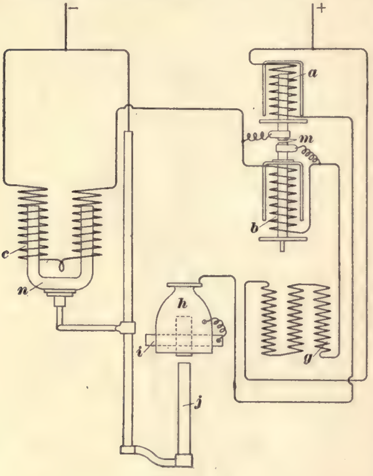


FIG. 48


FIG. 49

78. The voltage across the lamp terminals at the start is about 75. As the arc lengthens, owing to the burning away of the negative electrode, the voltage gradually rises until it reaches a fixed limit, when the shunt magnet acts to close the carbon contacts, thus short-circuiting the shunt magnet and permitting the starting magnet to again adjust the arc. This feeding occurs about once every hour.

Each negative electrode lasts from 150 to 200 hours; a positive electrode lasts about 4,000 hours. There is some residue from the burning, most of which falls into a tray in the bottom of the globe. This tray should be cleaned and the globe brushed out at each trimming; also, the center tube should be cleaned by running a small brush through it.

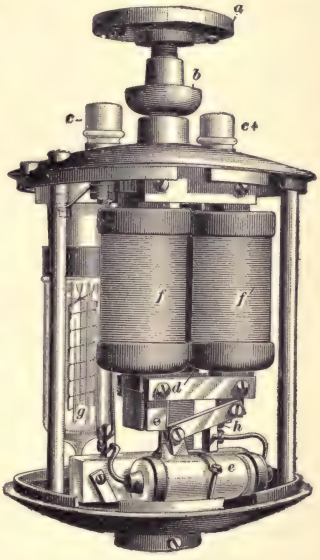


FIG. 50

The constant-current luminous-arc lamps consume about 320 watts and give off about 400 spherical candlepower, the specific consumption being about .8 watt per candlepower. The output of light is slightly greater than that of a 340-watt open-arc lamp or a 460-watt enclosed-arc lamp, and the distribution is better.

In a later type of magnetite luminous-arc lamp, the positive electrode, consisting of convoluted strips of laminated copper and iron, forms the stationary lower element of the lamp, and the magnetite tube, which is connected to the negative lamp terminal, forms the upper element. The feed is downwards, which somewhat

simplifies the lamp mechanism. Better light distribution is also obtained.

79. Automatic Mercury-Vapor Lamp.—The Cooper Hewitt type P lamp is so constructed that on closing the switch it will operate without the necessity of tilting the tube. In Fig. 50 is shown the lamp mechanism, and in Fig. 51 the connections of the operating devices. Corresponding parts in the two figures are lettered the same. In Fig. 50, *a* is the ceiling plate; *b*, the insulating joint; $c+$ and $c-$, Figs. 50 and 51, are the lamp binding posts; *d*, a resistance coil; *e*, the shifter, or circuit interrupter; *f* and *f′*, the inductance coils; *g*, the ballast; and *h*, an armature, which is drawn toward *f*, *f′* when these coils are energized.

The positive lamp terminal $c+$, Fig. 51, is connected to

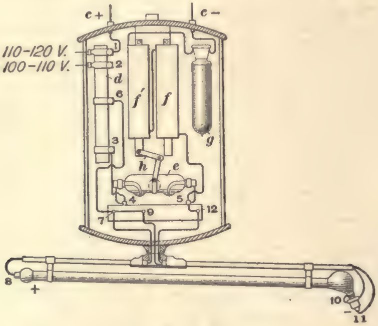


FIG. 51

terminal *1* or terminal *2* on the resistance coil, depending on the voltage of the circuit. The shifter consists of a glass vessel containing two electrodes, which are connected by mercury when the lamp is not operating. This vessel is mechanically connected to armature *h* and is rotated on its axis when *h* is drawn up; an indentation in the glass vessel then divides the mercury stream into two separate bodies and the rotation also causes the mercury to fall away from the contacts, thus opening the circuit through the shifter.

The lamp is started as follows: Close the switch; current now flows from $c+$ through *1* or *2–3–4–e–5–f–f′–g–c−*. The inductance coils are energized and armature *h* is drawn up, thus rotating shifter *e*, breaking the circuit through the shifter, and impressing a high electromotive force, due to the kick of the inductance coils *f*, *f′*, on the lamp tube terminals. The positive side of the lamp mechanism is connected to the positive tube terminal by path *6–7–8*, and to a starting band, consisting of a metallic coating painted on the outside of the enlarged chamber on the tube, by path *6–7–9–10*. The negative side of the lamp mechanism is connected to negative tube terminal *11*. The high electromotive force set up between *8* and *11*, and *10* and *11* overcomes the resistance between the tube terminals and starts the arc. The starting band assists by concentrating the stress, due to the kick of the inductance coils, at the surface of the mercury in the negative electrode, thus causing minute sparks at the mercury surface. As soon as the arc starts, the path of the current that maintains the arc is $c+$ *–1–6–7–8–*tube*–11–12–f–f′–g–c−*.

ELECTRIC SIGNS

FIXED ELECTRIC SIGNS

1. Electric signs are of almost endless sizes and varieties and some very striking effects are produced with them. There are many patented devices in use for producing electric-sign effects. While only a few of these are described in this Section, yet there is abundant chance for the electrician or wireman to exercise his ingenuity in devising new arrangements and devices to catch the public eye. The descriptions that follow are suggestive of innumerable schemes. There are two general classes of electric signs: those that have a fixed display and those that change either automatically or at the will of an operator.

2. Fixed electric signs may be classified as those in which the lights are arranged to illuminate a printed or a painted sign; those in which the lamps are concealed behind letter-shaped openings covered with translucent material through which the light shines; and those in which the lamps themselves are arranged in the form of letters, the bulbs being displayed. Combinations of any two or more of these methods may be used.

The user of an electric sign is addressing the public, and he naturally desires to address the greatest possible number of people for the longest possible time and in the most impressive way. The sign should be designed with these points in view. A sign that is legible only for short distances or only during the night while the lamps are burning is, generally speaking, of less value than one that can be read distinctly from a long distance and that is visible either by day or night.

ILLUMINATED SIGNS

3. Fig. 1 shows a sign that is distinct and legible either by day or night and that can be arranged single-faced or double-faced; that is, so that it can be read from one direction or from both. This sign consists of white letters on a blue enameled background surrounded by a border in which is placed a number of incandescent lamps, which are so arranged that the letters are brilliantly illuminated while the

FIG. 1

lamps are burning. The lamp sockets and wiring are concealed behind the border, and the wiring is very simple.

The making of such an enameled sign is an expensive operation, requiring special tools and facilities, but any electrician assisted by a sign painter should be able to make up a sign similar to that shown in Fig. 1. A modification that might in some cases be an improvement would be to arrange shades over the lamp bulbs, so as to conceal them from view and at the same time throw the light on the letters.

TRANSPARENT SIGNS

4. One sign manufacturer has had patented a method of

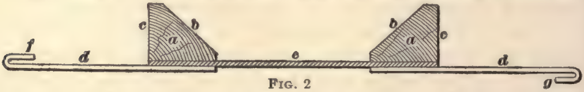
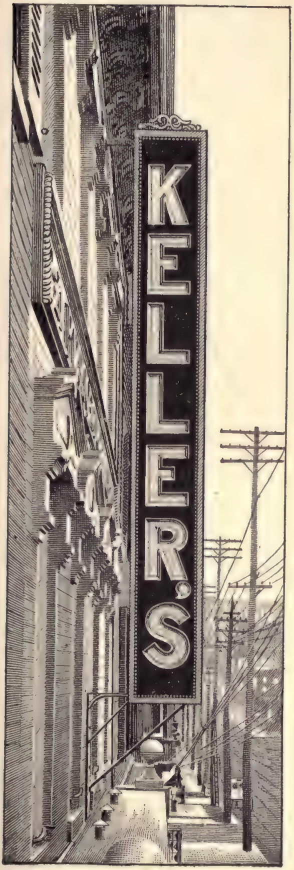


FIG. 2

making electric signs in which the letters or characters are



(a)

(b)

FIG. 3

outlined by a raised molding, leaving a hollow central portion that is covered with a light-tinted, wire-woven, translucent substance, behind which electric lamps are arranged. Fig. 2 shows a sectional view of a letter; *a* is the molding, of which the face *b* is covered with gold leaf and the side *c* tinted to harmonize with the dark background *d*. The letter-shaped opening outlined by the molding is covered with the translucent material *e*, back of which the lamps are placed. The hooks *f* and *g* enable any number of letters to be interlocked. Fig. 3 (*a*) shows the appearance by daylight of a sign made of such letters, and (*b*) shows the same sign at night.

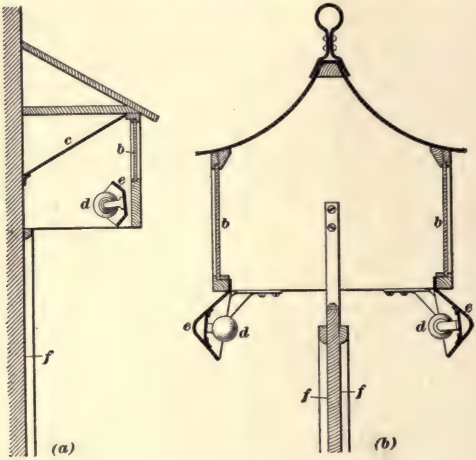


Fig. 4

5. Combination Sign.—Fig. 4 shows sectional views of a patented device in which electric lamps are used, both to illuminate a painted sign and to light a transparency; (*a*) shows a single-faced sign, and (*b*) a double-faced sign. In (*a*) the transparent sign *b* forms the front wall of a casing, across the opposite upper corner of which is a reflector surface *c* that throws the light of the row of lamps *d* out through

the transparency. Behind the lamps is a curved or V-shaped reflector *e*, which may be turned at any desired angle to direct a proper portion of the light on the painted sign *f* below the casing. The lamps are invisible, while the signs are well illuminated. The double-faced sign *b* is practically a duplicate of the single-faced sign. Transparent signs *b* are placed in each side of the hood, or casing, and there are two painted signs *f* and two rows of lamps *d*, each row having its curved reflector *e*.

EXPOSED-BULB SIGNS

6. One lamp may be used to illuminate a considerable portion of a painted sign or a transparency; but in order to form a letter of exposed lamp bulbs so that it will be intelligible at night, several lamps must be used. It is an object to keep the number of lamps as small as possible, not only to reduce the cost of the sign, but also to keep the cost of operation down. In Fig. 5 (*a*) is shown the result of an attempt to make the letter *E* with only six exposed lamp bulbs and no reflecting surfaces, while in (*b*) is shown the number and arrangement of lamps necessary to make the letter legible.

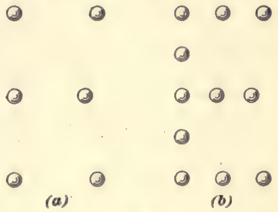
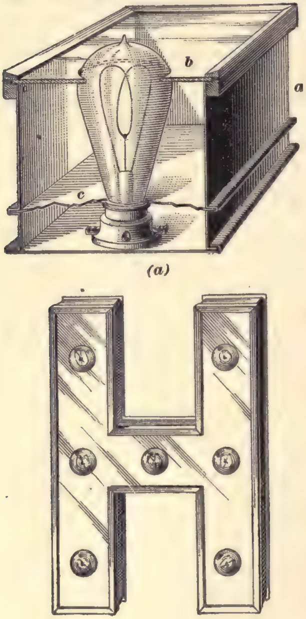


FIG. 5

7. By enclosing the lamps in boxes having the shape of the letter to be produced, and by using reflecting and distributing surfaces so that the light can be thrown only in the outline of the letter, fewer lamps may be used. Fig. 6 (*a*) shows a section of a patented letter that in reality is a combination of a transparency and an exposed-bulb sign. The letter, as patented, consists of a galvanized-iron body *a* with a translucent face *b* through which the ends of the lamp bulbs protrude. A white reflecting surface *c* and the white inner surfaces of the box throw nearly all the light out through the

translucent surface. Fig. 6 (b) shows a 24-inch letter H made in this way and lighted with only seven lamps. The translucent faces are white, so that the letters are equally legible by day or night.



(a)

(b)

Fig. 6

8. Doubled-Faced Signs.—Individual letters are sometimes cut from wood, painted with white-enamel paint so that they will be distinct in daylight, and covered with incandescent lamps, which bring out the outlines of the letters at night. In making up **double-faced signs,** of letters made in this way, it is well to bear in mind that the letters *A*, *H*, *I*, *M*, *O*, *T*, *U*, *V*, *W*, *X*, and *Y* appear the same whether viewed from the back or the front. It is often possible to use both faces of these letters. The other letters of the alphabet must be cut from material thin enough, so that when two letters are placed back to back they will have the same thickness as the double-faced letters.

Fig. 7 shows a large sign on a prominent corner in New York City. The letters are cut from 2-inch seasoned lumber, painted white, and fastened to a wide strip of bar iron, which serves to hold the sign in position. On the faces of the letters are rows of incandescent lamps, which make the sign very conspicuous at night. The dentist sign a short


Dr. de Walloff Dentist
DENTISTS
Levey
HAIR
SCALP
TREATMENT
A SPECIALTY
MANICURING
MARCEL
WAVING
DENTIST.
CLEANSER Levey DYER
12 W. 36
THEATRICAL CLEANSE

FIG. 7

distance from the corner is one of the type described in Art. **3**.

9. Examples of Large Signs.—The immense Butterick sign, Fig. 8, on the side of the Butterick Building, in New York City, can be seen from the New Jersey shore within a radius of several miles. The first letter is 68 feet high, while

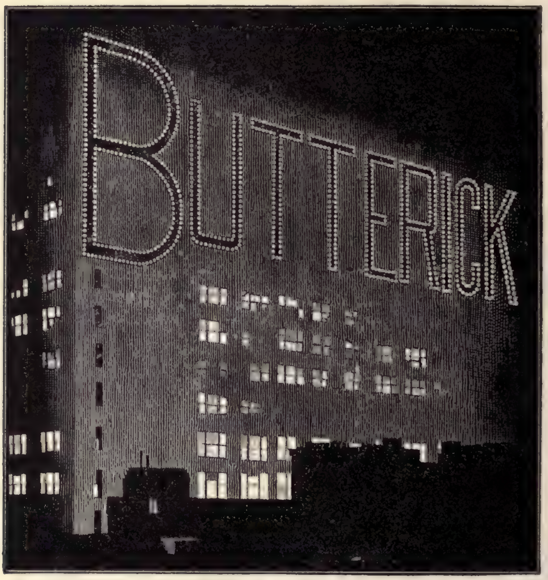


FIG. 8

the others are 50 feet. The two lines of lamps inscribing the outlines of the letters are 5 feet apart. The letters are painted in fast black on the brick wall. A light steel box construction about 6 inches high is spaced about 6 inches from the wall, to which it is fastened by means of expansion bolts. The box construction is made in sections about 10 feet long, with lamp sockets every 18 inches, and is placed around the

outlines of the letters. There are twelve hundred 4-candlepower lamps controlled by three switches, each switch having a separate panel box. From one panel runs twenty-four circuits and from each of the other two, sixteen circuits. The wiring is carried through the interior of the sign boxes.

10. The New York Edison Company has erected a sign, shown in Fig. 9, at its coal-storage plant at Shadyside, New Jersey, which can be seen plainly for several miles up and

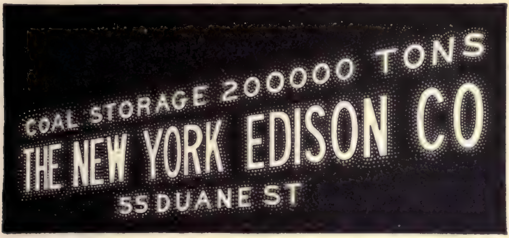


FIG. 9

down the New York side of the Hudson River. To support this sign, a framework requiring over 70,000 pounds of steel was put up. The sign contains eighteen hundred 8-candlepower lamps. A special 75-kilowatt generator and engine is used to supply the electricity.

The lamps used for electric signs are usually of smaller candlepower than those used for ordinary illumination; 4-, 6-, and 8-candlepower sizes are common. Sign lamps also have shorter and thicker bulbs, with the filament so coiled that the larger part of the light will be thrown out at the end.

CHANGEABLE SIGNS

CHANGES IN INTENSITY OF LIGHT

THERMOSTATS

11. The fixed, or permanent, signs thus far described may be made very attractive and of considerable value to the advertisers; but no sign arrests the attention of passers-by as does one in which there is apparent animation, especially if the changes or motions are surrounded with an air of mystery. In electric signs, changes so slight as the lighting and putting out of the lamps or changes in the intensity of the light will arrest the attention long enough for the passer-by to read what the advertiser has to say. Automatic devices may be arranged to switch off all the lamps of a sign together or part of them at a time. This is frequently done by means of a **thermostat**, an instrument in which an electric current heats a metal and causes it to expand until a circuit-opening device is made to operate so as to close or open a circuit, after which the heating current is cut off or so reduced that the metal cools and contracts and the device is operated in the reverse direction; this throws the heating coil into circuit again, and the series of operations are repeated indefinitely.

12. The Thermoblink.—Fig. 10 (*a*) shows a form of thermostat having the trade name **thermoblink,** and (*b*) shows the connections with a circuit of lamps. This device consists of metal strips arranged in the form of a triangle, around one leg of which is wound a coil *a* of fine wire that forms a part of a circuit through the lamps. When the current is first switched on, the end *b* of the triangle does not quite make contact with the end of a screw *b'* with which one

end of the lamp circuit connects; but a small current, not enough to light the lamps, flows through the coil *a* and heats it. The heat causes the metal around which the coil is wound to expand until the end of the triangle swings over and touches the contact screw *b′*; current enough to light the lamps then flows through the side *c* and the contact screw. The coil *a*, being shunted by the side *c*, soon cools and the triangle springs back to its normal position, thus

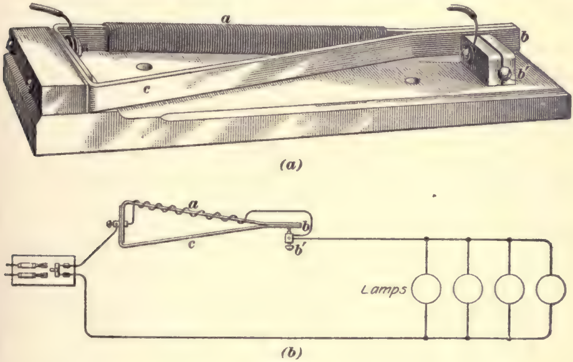


FIG. 10

breaking the contact between *b* and *b′* and putting out the lights. This process is repeated indefinitely or until the whole circuit is switched off.

In another form of the same device, a central tongue is made to swing both ways by the influence of a heating coil, one of two circuits being closed immediately after the other is opened. A retarding device holds the contact closed in either position until the pull becomes strong enough to open it with a snap.

13. Lamps With Thermostats.—It is now possible to obtain incandescent lamps that have **U**-shaped bimetallic thermostats in the bases, made as shown in Fig. 11. The two metals of which the **U**-shaped piece is formed have different rates of expansion under the influence of heat.

The **U** is wound with a coil of wire *a* connected in series with the lamp filament. When the lamp is connected to the circuit, it lights for an interval, until the coil heats and causes the **U** to spread and open the circuit, as shown

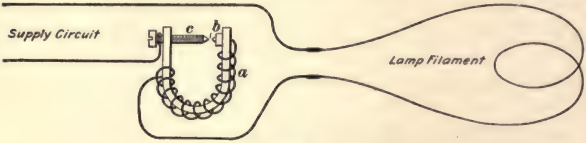


FIG. 11

at *b*. This stops the flow of current through the filament and puts out the lamp; the heating coil *a* soon cools and the contact *b* closes, thus again lighting the lamp. By means of an adjusting screw *c* the rapidity of the flashing may be regulated. The contact points at *b* are tipped with platinum.

14. Double-Filament Lamps.—Fig. 12 shows a sign lamp having a large and a small filament. The base contains a thermostat that causes the two filaments to light alternately. While on the circuit, such lamps are never entirely dark, but the intensity of the light changes enough to draw attention.

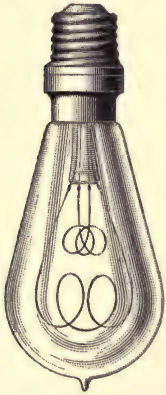


FIG. 12

15. Turnip Sign Lamps.—Fig. 13 (*a*) and (*b*) shows side and end views of a **turnip sign lamp,** so called because of its shape. The base contains a thermostat, and on the end opposite the base is a letter, word, or sentence to be displayed. The continual flashing calls attention to the advertisement.

16. Thermal Flashers.—Not over 2 amperes current can be broken by the thermostats thus far described, as the sparking, if a larger current were broken, would soon destroy the contacts. In Fig. 14 (*a*) is shown a **thermal flasher** made by the Solar Electric Company that will break

10 amperes, and in (*b*) is shown connections to a circuit of lamps. The carbon contacts *a* are normally separated, the upper one being fixed in position and the lower one attached to one end of a spring lever *b*, the other end of which is fixed at *c*. Near the fixed end of the lever *b* is attached the end of an expansion wire *d* that passes down through a tube and pulls the lever *b* downwards against the opposing action of a spring *e*, which may be either coiled, as shown, or flat. Around the expansion wire inside the tube is a coil of fine wire, called the heating, or resistance, coil, one end of which is in connection with the fixed end of the spring lever *b* and the other in connection with the upper, or fixed, carbon block *a*. These connections make the resistance coil a part of the circuit through the lamps.

(*a*)

(*b*)

Fig. 13

When current is turned on, it flows through the heating coil, which does not permit the passage of enough current to light the lamps of the circuit; but as the coil heats, the expansion wire inside stretches until the carbon blocks are drawn together by the spring *e* and the lamps light. The heating coil, now being shunted by the lever *b* and the carbon

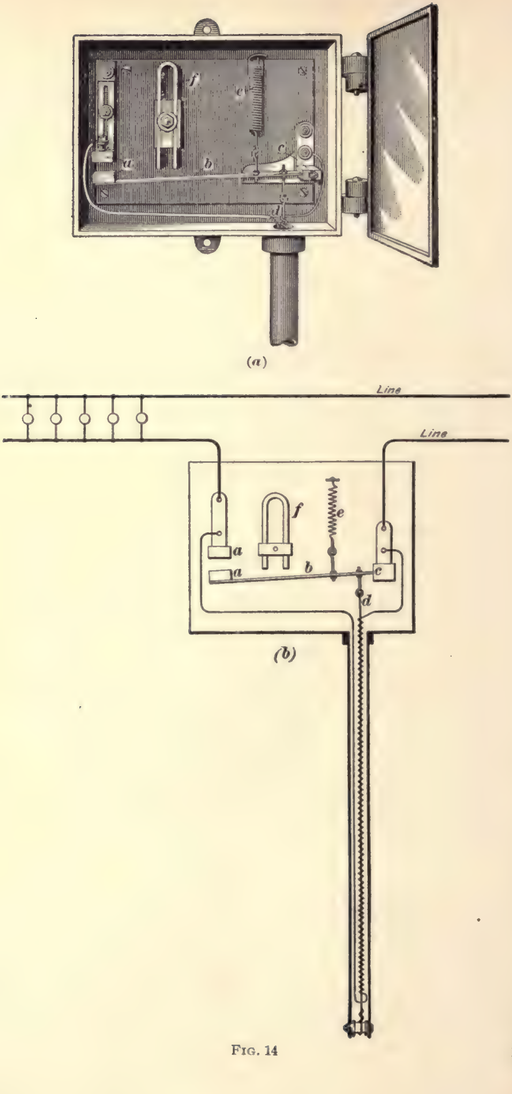


FIG. 14

blocks, soon cools, and the expansion wire contracts and pulls down on the lever against the combined holding power of the permanent horseshoe magnet *f* and the spring *e*. The pull of the expansion wire finally becomes so strong that the carbon blocks separate with a quick break. The resistance coil immediately begins to heat again and the process is repeated. Adjustments can be made on the regular flashers so that the lamps will light from eight to fourteen times per minute and so that they will remain lighted any desired portion of the time, from 50 to 90 per cent. Special thermostats of this type have been made to work once a minute and others to work fifty-six times a minute.

MECHANICAL FLASHERS

17. Double-Pole Flasher.—Various mechanical devices are in use for flashing lamps automatically. Figs. 15 and 17 show devices made by the Electric Motor and Equipment Company. In Fig. 15 (*a*) is shown a **three-circuit, double-pole, commutating switch,** or **flasher,** and in (*b*), a similar switch with the motor and one end casting removed. The rotation of the motor is transmitted through the belt and worm-gear to the shaft *a*, on which are as many disks *b* as there are circuits to be controlled. In Fig. 15 (*b*) only two disks are shown in place, the third being removed in order to show the mechanism. Near the rim of each disk is a series of holes, in any of which may be placed the pinions of steel rollers *c*. The rollers may be placed on either side of the disk, and the pinions are secured in place by screws through the rim of the disk, as shown at c'.

When the roller on one side of the disk presses against the jointed links *d* and forces them down until they are in line with each other, the switch arm *e* is forced over until the blades e' enter the spring clips *f*. The spring *g* is then under tension, tending to open the switch. A smaller shaft *h* below the main shaft *a* carries castings, each of which has two cams *i*, *j*. There are one set of links and one pair of cams for each disk. The links and cams shown in Fig. 15 (*b*)

are operated by the third disk, removed from shaft *a*. After the roller on one side of the disk has closed the switch and passed on away from the links, a roller on the other side strikes against the cam *i* and causes cam *j* to force the links

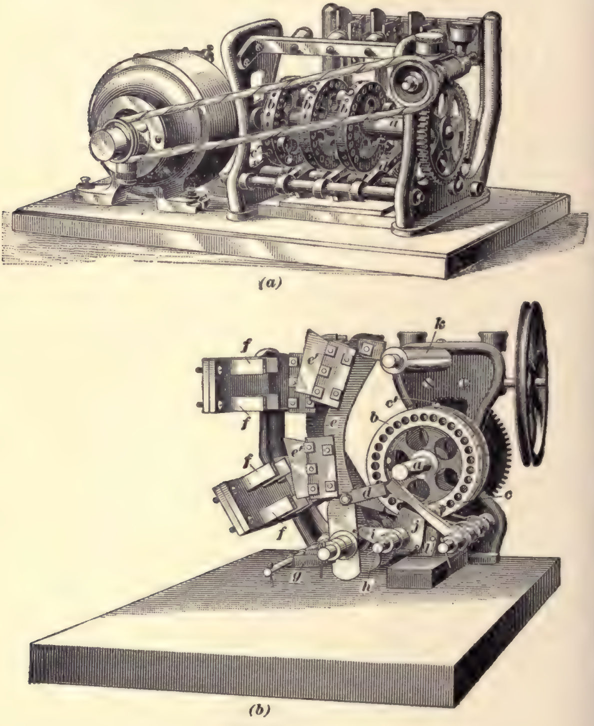


Fig. 15

out of line, when the spring *g* quickly pulls the switch open, a rubber bumper *k* taking up the jar. As soon as the roller has left cam *i*, the spring *l* pulls the cams back, so that the links are free to be forced down into line when the roller

next strikes them. The condition shown is that just after the switch has been opened and before the cams have snapped back into place.

18. The two blades *e'*, Fig. 15 (*b*), of each switch are insulated from the arm *e* that carries them. When the switch is closed, each blade makes contact with two clips *f*, as shown diagrammatically in Fig. 16. The upper clip of each pair is connected to the supply line, and the lower one to the lamp circuit. Each switch is therefore double pole.

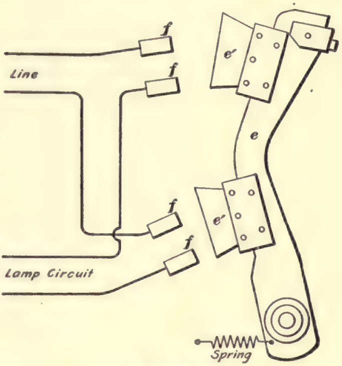


Fig. 16

19. Single-Pole Flasher.—Fig. 17 shows a portion of a smaller flasher that is single pole. The shaft *a* rotates and carries with it arms *b*, *b'*, etc. Arm *b* strikes against and raises a projecting switch arm *c*, and closes a switch against the action of a heavy coiled spring *d* tending to open it. The switch is locked in the closed position by a hook on one end of a casting *e*, on the other end of which is an arm against which the arm *b'* strikes at the proper time, and thus tips the casting enough to release the switch and allow it to fly open. After the arm *b'* has passed, the hooked end of the casting is held up in position by a lighter coiled spring *f*, and is ready to catch the switch for the next operation.

20. Time Switches.—Fig. 18 shows the principal parts of an **automatic time switch**, consisting of an ordinary double-pole knife switch, with the handle at right angles to its ordinary position, and a device that opens the switch automatically at a set time. In the position ordinarily occupied

by the switch handle is a special casting having a lip *a* that hooks behind the end of a lever *b* and holds the switch closed against the action of a spring *c* that tends to open it. Above the switch is a shelf bearing two pedestals *d*; the shaft supported by the pedestals carries on one end a slotted rectangular block *e* and on the other end a cam *f*. An ordinary alarm clock is placed on the shelf between the springs *g*,

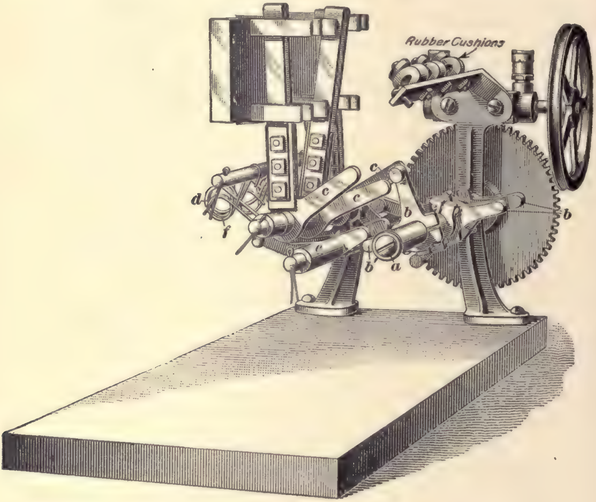


FIG. 17

so that the thumb piece for winding the alarm fits into the slot in the block *e*. When the alarm goes off, the thumb piece turns and causes the cam *f* to move the lever *b* enough to release the switch, which immediately flies open. A coiled spring *h* causes the lever *b* to return to its original position as soon as the pressure of the cam *f* is removed.

By the use of time switches, lamps may be left burning at night, to be automatically thrown off at any desired time. Similarly arranged switches are made both for closing and

for opening circuits, so that lamps can be made to light automatically at one hour and go out at another. These switches are useful for lighting the lamps of a sign or those

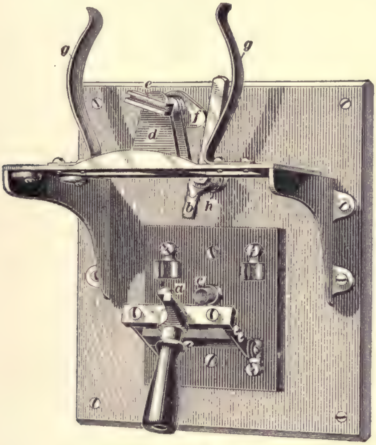


FIG. 18

in show windows on Sundays and holidays, and then extinguishing them after the travel by the store has nearly ceased for the night.

CHANGES IN DISPLAY

ELBLIGHT SYSTEM

21. There are in use many systems and devices by means of which the wording of a sign may be changed. The **Elblight system** consists of lighting boards, cables, and lamps with two-pin terminals.

The lighting boards are made by laying conductors *a*, *a*, Fig. 19, side by side parallel with each other, and so connecting them by suitable terminals to a source of electromotive force that adjacent conductors will be of opposite

polarity. Between the conductors is insulation *b*, *b*. The conductors are stranded, and when the board is compressed they flatten out until they are separated by about $\frac{1}{8}$ inch of insulation.

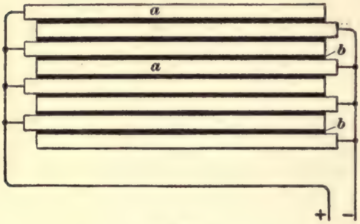


Fig. 19

22. The Elblight cables are made in a similar manner. Many strands of bare, fine copper wire are braided together as a cable and insulated, two insulated cables being fastened side by side when in use, as shown in Fig. 20. Fig. 21 (*a*) shows a lamp for use with a lighting board, and (*b*) shows a method of fastening the lamps to the cables. The lamp bases are porcelain and the prongs phosphor-bronze. The braiding of the cable strands is such that under ordinary conditions the prongs are firmly held without the clamp. The insulation on the cable is of a high-grade rubber, so that holes formed by the lamp prongs close immediately when the prongs are withdrawn.

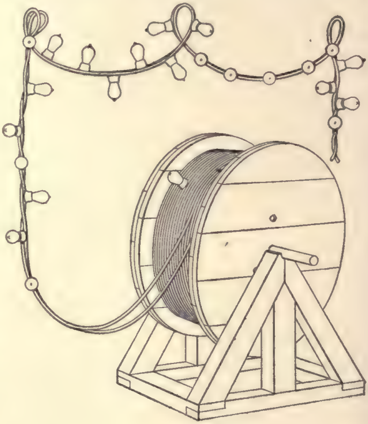


Fig. 20

All that is required to light lamps with either the board or the cable is to thrust the prongs through the insulation until they come in contact with the copper. In the board, the insulation between the

conductors usually consists of hard fiber or some other material that the prongs will not easily penetrate, so that short circuits are rare. Lamps may be arranged on the board in the form of any letter, figure, or character desired and may be changed, without great expense, to any other design. The cable is more useful for electric ornamentation than for electric-sign work, as it may be draped or looped along the walls of a room or a building, wound around pillars and covered with evergreen, with lamps stuck in at intervals, etc.

FIG. 21

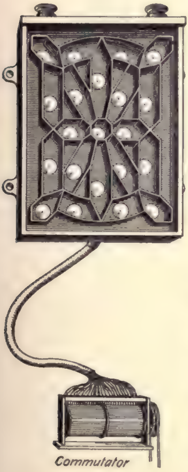


FIG. 22

TALKING SIGNS

23. Monogram Letters.—Various other devices are in use by which the positions of the lamps in a sign may be changed so as to display different letters; but to make such changes requires considerable time and trouble. Fig. 22 shows a group of twenty-one lamps arranged in metal troughs, or boxes, whose inside surfaces are whitened with a vitreous substance like enamel, so that they reflect the light outwards. This device, including the lamps and boxes, is called a **monogram letter,** or simply a **monogram;** with it, by lighting different groups of lamps, may be displayed any letter of the alphabet. In order to show any desired letter, it must be possible to control the lighting of each lamp independently of the others

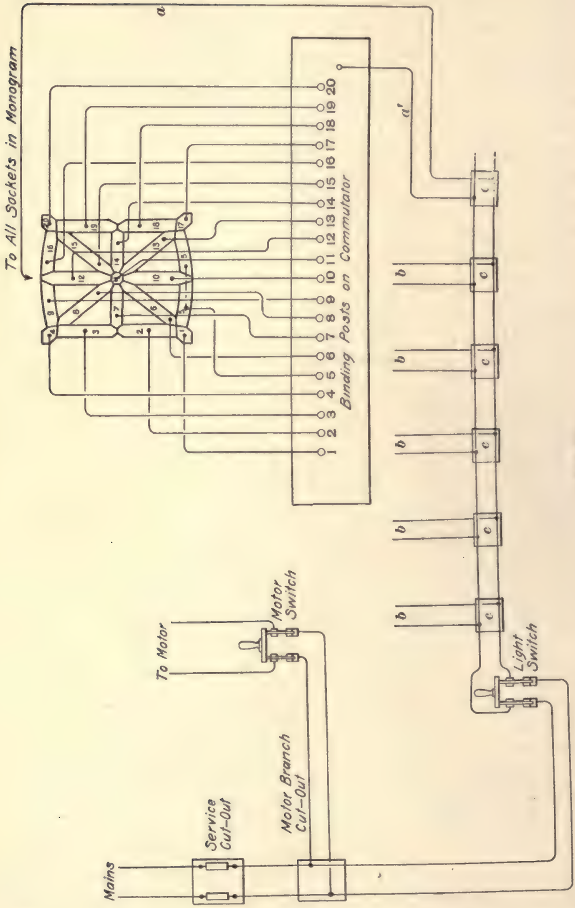

To All Sockets in Monogram
a
a'
Binding Posts on Commutator
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
b
c
To Motor
Motor Switch
Light Switch
Mains
Service Cut-Out
Motor Branch Cut-Out

FIG. 23

(with one exception). This necessitates a separate wire from one side of each lamp socket to a suitable controlling device, but the other side of each socket is connected to a common wire that leads directly to the supply circuit. The controlling device, or *commutator*, automatically changes connections so as to display letters in any desired order.

24. Fig. 23 shows the complete wiring of one monogram, with the exception of the lamp connections of the wire *a* common to all lamp sockets; these connections are omitted for the sake of clearness. The individual wires from the lamps lead to a series of binding posts *1* to *20* on the commutator. The two lamps numbered *5* in the monogram

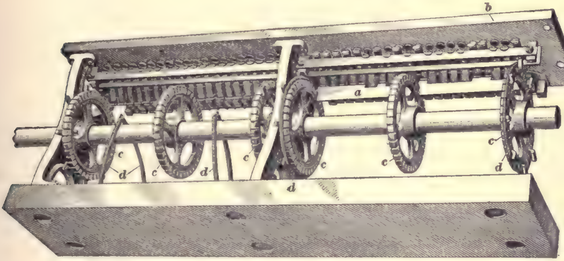
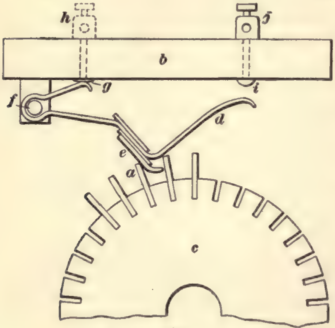


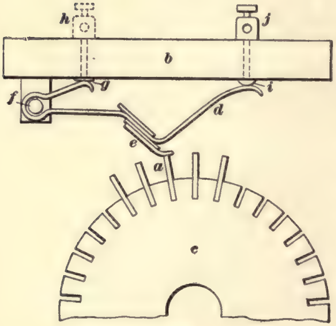
FIG. 24

are never lighted separately; hence, a common wire connects them with finger number *5* on the commutator. This is the exception previously referred to. Including the wire *a* common to all lamp sockets, there are twenty-one wire leading to each monogram. A wire *a′* connects the commutator with the side of the supply circuit opposite that with which the common wire *a* is connected. Circuits *b* lead to other monograms in the same sign; one wire of each circuit connects with one terminal of each lamp in a monogram and the other with the commutator belonging to that monogram. Each monogram circuit is connected to the supply circuit through double-pole cut-outs *c*. Another branch circuit leads to the motor that operates the commutator.

25. The commutator consists of a series of contact fingers, or springs, and a device for forcing them into a position where they close the circuits through the lamps. Fig. 24 is a view of two commutators, one having a letter bar *a* in position. The contact fingers are arranged underneath the slate top *b*. The rolled-steel letter bars, each having projections for raising the fingers necessary to light a letter, are slipped into slots in the rims of the wheels *c*, and are held in place by spiral springs *d* around the end wheels of each commutator. On the left-hand commutator these springs are shown off the slotted wheels and hanging on the shaft. The shaft is rotated by means of a motor, not shown, so that successive letter bars are brought under the fingers.



(a)



(b)

FIG. 25

26. Fig. 25 is a diagram showing a cross-section of the commutator; (*a*) shows a projection on a letter bar *a* just as it begins to raise a finger *d*, and (*b*) shows the finger raised to its full height. The letter bars do not make electrical contact with the fingers, but strike against metal shoulders *e* that are insulated from the fingers.

The fingers are phosphor-bronze springs clasped loosely about a bar *f* running lengthwise of the commutator. When a finger is raised, one end makes firm contact with a brass strip *g* on the under side of the slate cover. A single binding post *h* in connection with this brass strip serves for the copper wire *a'*, Fig. 23, connecting the commutator to the supply circuit. The other end of the spring *d*, Fig. 25 (*b*), makes contact with the round head *i* of a binding post *j*, one

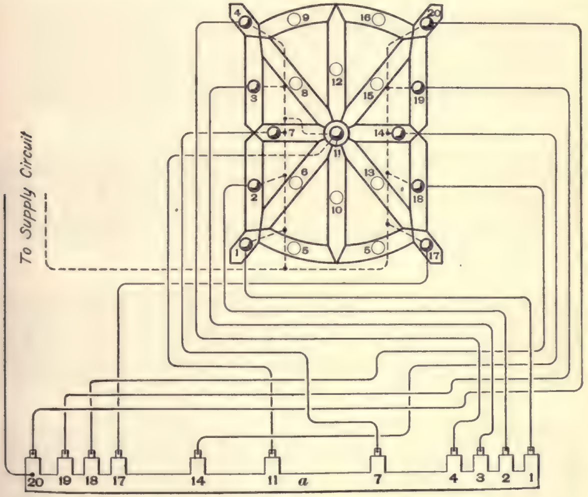


FIG. 26

of the twenty posts with which the lamps of the monogram are connected.

27. In Fig. 26 is shown a diagram of the connections that are active when the letter *H* is displayed. The letter bar *a* has projections that lift the fingers corresponding to the lamps needed. The lamps are numbered, and corresponding numbers are shown on the bar projections. This diagram represents conditions at one instant while the commutator is

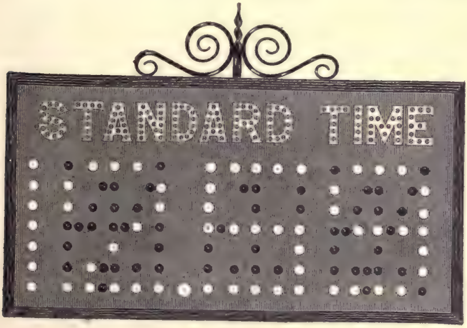
turning; as this bar passes out from under the springs, all the lamps go out, but immediately another bar with other projections moves under and another letter is displayed.

28. Each commutator holds forty bars; hence, each monogram can be made to display forty separate characters. A number of monograms arranged side by side with all their commutators operated by a single motor constitutes a

FIG. 27

talking sign, and may be made to flash forty words or sentences in succession. The same series of expressions may be flashed a whole evening without any supervision whatever from an attendant, or the attendant may substitute other bars as often as desired so that new expressions will be displayed. Fig. 27 shows four of the forty expressions one sign may be made to flash every night.

29. Talking Clock.—Fig. 28 shows an arrangement of electric lamps for displaying time; (*a*) and (*b*), respectively, show two successive displays. The lamps are differently arranged than in the letter monograms previously described,



(*a*)

(*b*)

FIG. 28

and each group contains only the number of lamps needed for the figures it must display. For example, the first group displays only the figure *1*, and hence contains but a single row of lamps; the second and fourth groups must

be capable of displaying any numeral from *0* to *9*, inclusive, and the third group any numeral from *0* to *5*, inclusive. A commutator operated in synchronism with the movements of a clock changes the contacts so that the time display is changed once every minute.

30. Carriage Calls.—Fig. 29 shows a **carriage call** that is very useful where a number of carriages are waiting

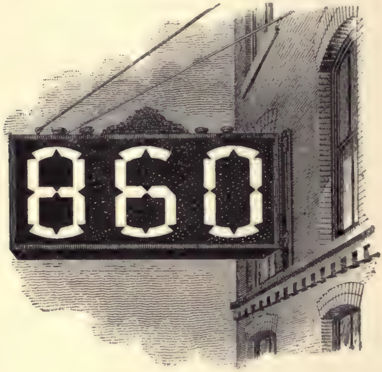


FIG. 29

for persons emerging from large assemblies, as at theaters. This call consists of three groups of lamps arranged in boxes with reflecting interiors and frosted-glass covers. The lighting of the lamps is controlled by a device somewhat similar to the commutator used with the talking sign, except that the carriage-call controlling device is operated by an attendant. Any number from *0* to *999*, inclusive, may be displayed on the call shown. On arrival, each carriage occupant and driver is given a number, and when the carriage is wanted this number is displayed on the carriage call, which is in plain view of all the drivers.

ELECTRIC HEATING

HEATING EFFECTS OF ELECTRIC CURRENTS

1. When a current of electricity flows through a conductor, work is done proportional to the square of the current I, the resistance R of the conductor, and the time t; that is, the work in joules is equal to $I^2 R t$, where I is in amperes, R in ohms, and t in seconds. All this work is converted into heat, which raises the temperature of the conductor and its surroundings.

In the generation and transmission of electricity, this production of heat is very undesirable and is avoided as much as possible by using conductors of low resistance or by transmitting the energy at high pressure and correspondingly low current. Ordinarily, in transmission work, the size of the conductors to be used is determined by the allowable pressure drop rather than by the heating effect, but it is sometimes necessary to consider the heating effect of electric currents. This is especially the case when wires are to be used in underground ducts, in molding, or other confined locations.

2. When the temperature of a wire is higher than that of its surroundings, heat escapes from the wire. A wire with a rough and blackened surface loses its heat more rapidly than one with a bright, shiny surface. Table I gives the heating effect of currents in bright and black wires, respectively, in still air. The figures in the body of the table are the diameters of the wires in mils. For example, to carry 1,000 amperes with a rise of 80° C. in still air requires a

TABLE I

HEATING EFFECTS OF CURRENTS

(Bare Copper in Still Air)

Amperes	Rise in Temperature. Degrees Centigrade							
	10		20		40		80	
	Bright	Black	Bright	Black	Bright	Black	Bright	Black
	Diameters of Wires. Mils							
1,000						968	911	750
950						930	878	723
900						893	844	695
850						858	809	666
800					1,000	823	771	638
750					950	785	734	610
700				960	900	748	696	580
650				910	850	708	660	550
600				858	800	668	621	518
575				833	775	648	603	503
550		995	980	808	750	628	583	488
525		978	948	780	725	607	563	461
500		960	913	751	700	584	543	455
475		925	880	723	675	563	523	439
450		895	843	696	648	541	501	421
425		860	808	669	620	520	479	406
400	1,000	820	770	641	592	498	457	387
375	950	783	731	612	564	475	435	369
350	900	745	690	581	536	452	413	350
325	850	708	654	550	506	428	390	331
300	800	668	615	519	475	403	366	312
275	750	628	575	487	444	377	341	292
250	696	586	534	453	412	351	317	272
225	642	545	494	419	379	323	291	252
200	586	500	453	384	345	296	265	229
175	530	454	406	349	310	266	239	208
150	470	404	360	311	274	226	210	194
125	408	352	308	270	235	206	182	161
100	343	300	258	226	195	170	150	135
90	315	272	237	208	178	158	137	123
80	286	246	214	196	161	143	124	112
70	259	220	190	170	143	127	110	100
60	226	194	167	150	125	112	97	87
50	191	167	142	130	106	95	82	74
40	156	140	117	108	86	78	68	61
30	120	111	90	85	66	60	54	48
20	82	76	63	60	45	44	40	36
10	40	38	37	35	30	28	26	24

TABLE II

HEATING EFFECTS OF CURRENTS

(*Carrying Capacity of Insulated Wire in Moldings*)

Amperes	Rise in Temperature. Degrees Centigrade								
	5	10	15	20	30	40	50	60	70
	Diameters of Wires. Mils								
300					446	411	386	367	354
280					427	393	369	350	338
260				450	409	375	352	333	321
240				430	390	356	333	315	304
220			436	408	370	337	315	298	285
200		448	414	386	350	317	295	280	268
190		437	403	375	339	308	286	270	258
180		425	391	364	328	298	277	260	249
170		411	378	352	317	287	266	250	239
160		398	364	340	305	276	256	241	229
150	445	383	351	326	293	265	244	230	218
140	431	370	338	312	281	253	232	220	206
130	417	354	322	300	269	240	220	208	195
120	400	339	308	285	255	228	208	195	182
110	383	322	292	270	240	214	195	182	170
100	362	302	276	253	223	200	182	168	158
90	343	284	259	237	208	185	168	154	143
80	322	264	240	218	192	169	153	139	130
70	300	242	220	198	174	152	139	123	116
60	275	220	195	175	155	135	122	108	101
50	250	195	175	152	132	118	104	91	86
40	217	169	144	128	110	95	85	75	70
30	178	136	115	100	85	73	66	58	54
20	132	100	71	69	59	50	45	40	37
10	78	58	42	35	30				

TABLE III

DIAMETERS OF WIRES OF VARIOUS MATERIALS THAT WILL BE FUSED BY A CURRENT OF GIVEN STRENGTH

(W. H. Preece, F. R. S.)

Current. Amperes	Diameters. Inch								
	Copper	Aluminum	Platinum	German Silver	Platinoid	Iron	Tin	Tin-Lead Alloy	Lead
1	.0021	.0026	.0033	.0033	.0035	.0047	.0072	.0083	.0081
2	.0034	.0041	.0053	.0053	.0056	.0074	.0113	.0132	.0128
3	.0044	.0054	.007	.0069	.0074	.0097	.0149	.0173	.0168
4	.0053	.0065	.0084	.0084	.0089	.0117	.0181	.021	.0203
5	.0062	.0076	.0098	.0097	.0104	.0136	.021	.0243	.0236
10	.0098	.012	.0155	.0154	.0164	.0216	.0334	.0386	.0375
15	.0129	.0158	.0203	.0202	.0215	.0283	.0437	.0506	.0491
20	.0156	.0191	.0246	.0245	.0261	.0343	.0529	.0613	.0595
25	.0181	.0222	.0286	.0284	.0303	.0398	.0614	.0711	.069
30	.0205	.025	.0323	.032	.0342	.045	.0694	.0803	.0779
35	.0227	.0277	.0358	.0356	.0379	.0498	.0769	.089	.0864
40	.0248	.0303	.0391	.0388	.0414	.0545	.084	.0973	.0944
45	.0268	.0328	.0423	.042	.0448	.0589	.0909	.1052	.1021
50	.0288	.0352	.0454	.045	.048	.0632	.0975	.1129	.1095
60	.0325	.0397	.0513	.0509	.0542	.0714	.1101	.1275	.1237
70	.036	.044	.0568	.0564	.0601	.0791	.122	.1413	.1371
80	.0394	.0481	.0621	.0616	.0657	.0864	.1334	.1544	.1499
90	.0426	.052	.0672	.0667	.0711	.0935	.1443	.1671	.1621
100	.0457	.0558	.072	.0715	.0762	.1003	.1548	.1792	.1739
120	.0516	.063	.0814	.0808	.0861	.1133	.1748	.2024	.1964
140	.0572	.0698	.0902	.0895	.0954	.1255	.1937	.2243	.2176
160	.0625	.0763	.0986	.0978	.1043	.1372	.2118	.2452	.2379
180	.0676	.0826	.1066	.1058	.1128	.1484	.2291	.2652	.2573
200	.0725	.0886	.1144	.1135	.121	.1592	.2457	.2845	.276
225	.0784	.0958	.1237	.1228	.1309	.1722	.2658	.3077	.2986
250	.0841	.1028	.1327	.1317	.1404	.1848	.2851	.3301	.3203
275	.0897	.1095	.1414	.1404	.1497	.1969	.3038	.3518	.3417
300	.095	.1161	.1498	.1487	.1586	.2086	.322	.3728	.3617

bright wire 911 mils in diameter, but a black wire of only 750 mils diameter will carry the same current with the same temperature rise. Table II gives the heating effects of electric currents in insulated wires used in moldings. Heat escapes more readily from a wire to its insulation and the moldings than from a bright, bare wire to still air; for

TABLE IV

CARRYING CAPACITY OF GERMAN-SILVER WIRE

Number B. & S.	Circular Mils	Maximum Current Amperes	Feet per Ohm
10	10,381	6.8	60.90
11	8,234	5.7	47.60
12	6,529	4.8	37.80
13	5,178	4.0	29.90
14	4,106	3.4	23.70
15	3,257	2.8	18.80
16	2,583	2.4	14.90
17	2,048	2.0	11.80
18	1,624	1.7	9.40
19	1,288	1.4	7.25
20	1,021	1.2	5.91
21	810	1.0	4.69
22	643	.83	3.72
23	509	.70	2.95
24	404	.59	2.33
25	320	.49	1.85
26	254	.42	1.47
27	201	.35	1.16

example, according to Table I, to carry 300 amperes with 40° C. temperature rise in still air requires a bright wire 475 mils in diameter, while according to Table II an insulated wire in molding to do the same thing need be only 411 mils in diameter.

3. Table III gives the currents that will just fuse, or melt, wires of different materials. The fusing effect of a

current depends on the readiness with which heat can escape from the wire. If a very short wire is clamped between terminals, heat will escape to the terminals; if a fuse is installed where air circulates freely, the air-currents will carry away heat, etc. For these reasons, fuses must be of sufficient length so that the heat imparted to the terminals cannot appreciably change the melting point; they must also

TABLE V

CARRYING CAPACITY OF GALVANIZED-IRON WIRE

Number Washburn & Moen Gauge	Circular Mils	Maximum Current Amperes	Feet per Ohm
3	59,536	51.5	645.0
4	50,625	45.5	549.0
5	42,849	40.0	463.0
6	36,864	35.5	398.0
7	31,329	31.3	337.0
8	26,244	27.5	283.0
9	21,904	23.8	236.0
10	18,225	20.6	196.0
11	14,400	16.9	155.0
12	11,025	13.5	119.0
13	8,464	10.7	91.4
14	6,400	8.4	69.1
15	5,184	7.1	56.0
16	3,969	5.7	42.8
17	2,916	4.3	31.4

be installed where air-currents cannot affect them. Fuses, therefore, are usually 1 inch or more long and are enclosed.

In the absence of air, a conductor will carry a much larger current without fusing than if air is present. For this reason, in rheostats and electric-heating apparatus, where a high current density in the conductors or an intense heat is desirable, the wire is embedded in cement, enamel, or other substance, which not only insulates the conductors, but also

excludes the air from around them. The incandescent lamp affords an example of the advantage of excluding air from a highly heated conductor. If even a very small quantity of air remains in a lamp globe, the life of the lamp will be

TABLE VI

CARRYING CAPACITY OF TINNED-IRON WIRE

No. B. & S.	Area Circular Mils	Maximum Safe Current With Wooden Frame Amperes	Maximum Safe Current With Iron Frame Amperes	Safe Current for 1 Minute	Feet per Ohm	Pound per Foot	Ohms per Inch of a Spiral Wound on .4-Inch Mandrel
8	16,509	17.40	20.30	43.6	250.00	.04000	.0050
9	13,094	14.60	17.10	36.6	173.00	.03300	.0066
10	10,381	12.30	14.30	30.8	137.00	.02751	.0095
11	8,234	10.30	12.00	25.8	108.00	.02182	.0131
12	6,529	8.70	10.10	21.7	86.40	.01730	.0182
13	5,178	7.30	8.50	18.3	68.50	.01372	.0245
14	4,106	6.10	7.10	15.3	54.30	.01089	.0353
15	3,257	5.10	6.00	12.9	43.10	.00863	.0492
16	2,583	4.30	5.00	10.8	34.10	.00685	.0690
17	2,048	3.60	4.20	9.1	27.10	.00543	.0960
18	1,624	3.00	3.50	7.6	21.40	.00430	.1345
19	1,288	2.50	2.90	6.3	16.50	.00341	.1963
20	1,021	2.20	2.50	5.4	13.50	.00271	.2636
21	810	1.80	2.10	4.5	10.70	.00231	.3725
22	643	1.50	1.77	3.8	8.49	.00184	.5220
23	509	1.30	1.49	3.2	6.73	.00146	.7350
24	404	1.08	1.20	2.3	5.34	.00116	1.035

much shortened; and if the filament were in open air, it would immediately be consumed.

4. The resistance wire in rheostats and in electric-heating apparatus, if properly protected from the air, may be

operated at red heat without material injury; but this is seldom done, because it is difficult to maintain good insulation at such high temperatures, and, moreover, such intense heat in these appliances is seldom necessary. Tables IV, V, and VI give the safe carrying capacities of various materials used for rheostats and electric-heating appliances. These figures are for continuous service in open air; for intermittent service, as in motor-starting rheostats, or for service in the absence of air, considerably more current can be carried safely, as indicated by the fifth column in Table VI.

APPLICATIONS OF ELECTRIC HEAT

GENERAL CONSIDERATIONS

5. Advantages.—In the electrical devices thus far considered, the development of heat has been an undesirable incident rather than an object. Under some conditions, however, it becomes highly desirable and possibly economical to convert electricity into heat. Some of the advantages of electric heat are as follows: (1) Its instant availability on closing a switch; (2) its perfect control, as heat may be obtained by its use in almost any intensity desired; (3) its perfect adaptability, as it may be applied to the exact location desired and in such a way that only very little heat escapes to the surrounding air or other objects; (4) the absence of smoke, flame, dust, poisonous gases, etc.; (5) the absence of fuel, ashes, etc. to be handled, or fires to be maintained; (6) the decreased danger from fire or explosions.

6. Effect on Central Station.—The applications of electric heat are very numerous, and fortunately for the interests of central-station owners and managers, most of these applications call for electric power during those hours when the station and the transmission system are not otherwise loaded to their full capacity. The addition of a *day load* to an ordinary lighting station is a source of considerable

profit to the station, inasmuch as such a load calls for no additional investment in generating equipment or in transmission lines, but permits the use of apparatus already installed at more nearly a constant load. With a good day load of motors or heating apparatus, engines and generators that would otherwise be idle and useless all day may be kept running at a considerable profit.

It is evident, then, that a station can afford to sell power during its periods of light load cheaper than during its maximum load, or, as commonly called, its *peak of load;* and many stations, in order to encourage a day load, offer special rates or other inducements for the use of motors, heating appliances, etc. that are ordinarily in use only during the day. Central-station managers should therefore be familiar with all electrical devices that may add to day loads, and should lose no opportunity to impress the public with the advantages to be obtained by the use of electricity. Electric heating presents a very promising field for such work.

7. Relative Costs.—The greatest arguments in favor of electric heating are its convenience and cleanliness; these in many cases are sufficient to overbalance the objection of increased cost. The relative cost of heating by electricity and by burning coal or gas depends on the continuity of the service required, as well as on the relative prices of electric power and of fuel. If a small amount of heat is required intermittently for short periods only, as for heating flat irons, it may prove more economical to use an iron that is heated electrically rather than to maintain a fire in a range, with its great waste of heat. In any case, it has been found that electric power at $2\frac{1}{2}$ cents per kilowatt-hour is about equal to gas at $1 per thousand feet, and that for cooking and miscellaneous heating, electric power at 4 to 5 cents per kilowatt-hour can compete successfully with coal at from $6 to $7.50 per ton.

THAWING FROZEN WATER PIPES

8. General Method.—The process of thawing frozen water pipes by electricity consists simply in sending through the pipe a current of electricity large enough to heat it. Alternating current is generally used, because almost any current strength desired can be easily obtained. In cities and towns where the winters are severe, many of the central stations provide special transformers, each having a secondary winding of a few turns of very heavy copper capable of carrying large currents. A transformer, together with the necessary cables, terminal clamps, measuring instruments, rheostats, etc., is mounted on a wagon or sled, and one or more such outfits are kept in almost continuous use through the freezing weather.

When a request is made for the services of the pipe-thawing outfit, it is hauled to the desired place, the terminals of the primary coil connected to the high-voltage lighting circuit, the terminals of the secondary coil to the frozen section of the pipe, one at each end, and an electric current of the proper strength turned on. The current strength should be suitable for the work to be performed; a large pipe of low resistance will require a larger current than a small pipe. Too large a current may injure the pipe; hence, it is better to use a more moderate current for a longer period of time. The length of time required to produce running water in pipes that are frozen solid varies inversely as the square of the current used.

9. Pipe-Thawing Data.—Table VII gives figures obtained in practice, showing the diameters and lengths of frozen pipes, and the amperes, volts, and time required to produce running water in each size. These results are probably a fair sample of what will always be obtained in practice, but are too inconsistent to permit the making of definite rules to be followed in all cases. For example, a 1-inch pipe 700 feet long embedded in solidly frozen ground required 175 amperes for 5 hours, while another pipe of the

TABLE VII

PIPE-THAWING DATA

Diameter Inches	Length Feet	Material	Amperes	Volts	Time Minutes
½	50	Lead	250	15	5
½	50	Iron	250	20	5
½	70	Iron	300	16	15
½	100	Iron	150	20	45
⅝	180	Lead	185	35	15
¾	40	Iron	300	50	8
¾	60	Iron	320	110	25
¾	75	Iron	100	50	5
¾	80	Iron	300	110	23
¾	100	Iron	135	55	10
¾	100	Iron	300	110	11
¾	150	Lead	250	50	12
¾	200	Iron	110	50	6
¾	200	Iron	120	50	1
¾	240	Iron	250	52	30
¾	250	Iron	120	50	10
¾	250	Iron	400	50	20
¾	380	Iron	300	30	10
1	45	Iron	140	220	17
1	90	Iron	280	110	10
1	100	Iron	175	220	15
1	150	Iron	200	40	20
1	150	Iron	280	110	120
1	220	Iron	60	105	75
1	250	Iron	400	50	20
1	250	Iron	500	50	20
1	600	Iron	60	50	60
1	700	Iron	175	55	300
1¾	130	Iron	340	110	90
2	20	Iron	2,000	6	180
2	50	Iron	500	50	120
2	60	Iron	160	50	4
2	300	Iron	250	52	150
4	800	Iron	300	50	180
6	400	Iron	800	110	70
8	700	Iron	1,000		2,400

same diameter and 600 feet long, but much less solidly frozen, required only 60 amperes for 1 hour. It is very seldom that an ordinary house pipe requires more than from 30 to 50 volts and 300 amperes.

10. Thawing Transformers.—The **thawing transformer** should be compact and easily portable. If specially designed, the transformer usually has a large magnetic leakage, so that with heavy secondary currents there will be a considerable drop of voltage; in fact, such a transformer may be short-circuited for several minutes without injury. This design makes the transformer so bulky that it is used only for work requiring fairly low secondary voltages; for higher voltages, an ordinary lighting transformer with a choke coil in series is used. The choke coil accomplishes the same object as the magnetic leakage in the special transformers.

11. Connections.—There should be very little resistance in the secondary circuit; that is, the secondary mains should be short, and all contacts should be made secure. In thawing house piping, one secondary lead is usually connected to a faucet and the other to the pipe where it enters the house, to a hydrant, or to a faucet in a neighboring house, the object being to send the current through all the frozen section. In thawing street mains, connections may be made to two hydrants or to one hydrant and the pipe beyond the frozen section, as shown in Fig. 1.

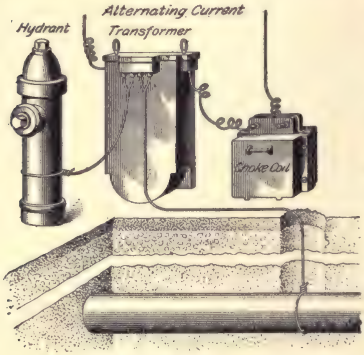


FIG. 1

WELDING

12. Thomson Welding Process.—By the ordinary process of welding, two pieces of metal are heated to the proper welding temperature and then, while still hot, are hammered together as one piece. Many welding operations that would be very difficult by this process may be easily performed by aid of electric current; that is, by the process of **electric welding.**

The **Thomson welding process,** which is more widely used than any other, is illustrated in Fig. 2. Alternating current is used for the same reason as given for its use in thawing frozen water pipes; namely, because a large current at a low voltage is thereby easily obtained. The current from an alternator *a* flows through the primary coil *d* of a transformer *b* by way of a switch *o*. A regulator *r*—preferably an adjustable reactance coil, though an adjustable resistance could be used—enables the primary current to be adjusted as desired. The laminated core *c* passes through both the primary coil *d* and the secondary coil *e*. The secondary coil consists of a very few turns, sometimes only one, of heavy copper, and has its terminals connected to the water-cooled clamps *f*, *g* holding the pieces *l*, *m* to be welded. Handles *h*, *k* operate the cams, by which pieces *l*, *m* are clamped. One clamp is movable, so that the pieces may be forced together when hot enough; this is sometimes done by hand and sometimes automatically by air pressure, weights, or springs.

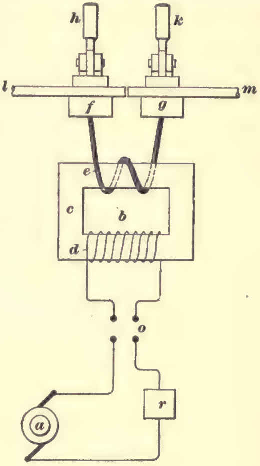


FIG. 2

13. Only a very low voltage is needed in the secondary circuit, but a current as high as 60,000 amperes per square inch may be necessary in welding some metals, as for example, copper. A low frequency, 50 cycles or less is preferred, especially for heavy work where the current density is very great, because high frequency together with high-current density causes high-inductive effect with a corresponding reduction of the power factor of the system.

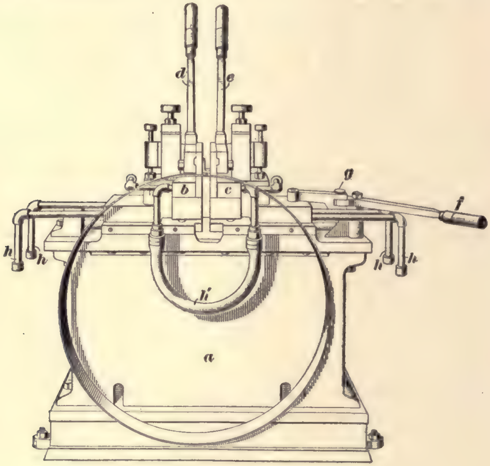


FIG. 3

14. Fig. 3 shows a Thomson welder for miscellaneous work up to 6-square-inch cross-section. A flat iron hoop is shown in position for welding, but different forms of clamps permit the handling of a variety of work. The transformer is contained in the base *a* of the welder, and the work is held by clamps *b*, *c*, operated by handles *d*, *e*. A lever *f* and a toggle *g* serve to force the clamp *c* toward *b* when the proper heat is attained. Water is circulated through the clamps by means of pipes *h*, *h'*, *h*. The pipe *h'* is a piece of rubber hose, which affords the necessary flexibility and also

prevents the passage of current between the clamps by way of the pipe. The current can pass from one clamp to the other either by crossing the joint to be welded or by going around the unjointed portion of the hoop; much the larger portion takes the shorter path across the joint between the clamps and heats the abutting ends of the hoop. The welder just described is a simple type; for some special work, welders are used in which hydraulic pressure is applied and regulated automatically.

15. Welding Transformer.—In Fig. 4 is shown one style of welding transformer that will illustrate the principles of all. This transformer has two laminated cores, one of

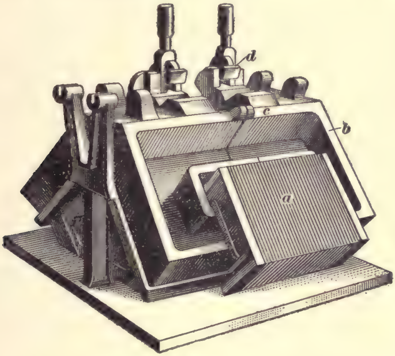


FIG. 4

which is shown at *a*. Linked with each core is a heavy copper casting *b* that forms the secondary winding of only one turn. A slit *c* between the clamps *d* compels the secondary current to pass through the work held between the clamps. The primary coil is not shown in the figure, but its place is in the recess shown in the secondary casting. In such a transformer there can be only very little magnetic leakage, and the secondary current may be very large. The secondary circuit of a welding transformer may take any form most convenient for clamping and holding the work.

TABLE VIII

POWER REQUIRED FOR ELECTRIC WELDING

Iron and Steel Distance Between Clamps = 2 × Diam.					Brass Distance Between Clamps = 3 × Diam.					Copper Distance Between Clamps = 4 × Diam.				
Area Square Inches	Watts in Primary of Welders	Time in Seconds	Horsepower Applied to Dynamos	Foot-Pounds	Area Square Inches	Watts in Primary of Welders	Time in Seconds	Horsepower Applied to Dynamos	Foot-Pounds	Area Square Inches	Watts in Primary of Welders	Time in Seconds	Horsepower Applied to Dynamos	Foot-Pounds
.5	8,550	33	14.4	260,000	.25	7,500	17	12.6	117,000	.125	6,000	8	10.0	44,000
1.0	16,700	45	28.0	692,000	.50	13,500	22	23.2	281,000	.250	14,000	11	23.4	142,000
1.5	23,500	55	39.4	1,191,000	.75	19,000	29	31.8	508,000	.375	19,000	13	31.8	227,000
2.0	29,000	65	48.6	1,738,000	1.00	25,000	33	42.0	760,000	.500	25,000	16	42.0	369,000
2.5	34,000	70	57.0	2,194,000	1.25	31,000	38	52.0	1,087,000	.625	31,000	18	51.9	513,000
3.0	39,000	78	65.4	2,804,000	1.50	36,000	42	60.3	1,390,000	.750	36,500	21	60.6	700,000
3.5	44,000	85	73.7	3,447,000	1.75	40,000	45	67.0	1,659,000	.875	43,000	22	72.1	872,000
4.0	50,000	90	83.8	4,148,000	2.00	44,000	48	73.7	1,947,000	1.000	49,000	23	82.1	1,039,000

16. Power Required for Electric Welding.—The time required for making a weld varies inversely with the amount of power supplied; that is, the greater the power the shorter the time, and the less the power the longer the time. Metals that are deteriorated by being heated, such as copper, brass, and tool steel, must be welded rapidly. The pressure must be great enough to crowd out from the weld all metal harmed by the heat.

Table VIII, given by the Thomson Electric Welding Company, shows the power required for welding iron, copper, and brass of varying cross-sections. Tests have shown that from 70 to 75 per cent. of the power supplied is actually used in making the weld, so that there is comparatively little heat wasted. Although there is a great loss of heat in the steam engine, and also some loss in the dynamo, it has been found that the fuel cost for electric welding is but little more than for welding by the ordinary process, because in the electric process, nearly all the heat is applied just where it is wanted.

17. Advantages.—Electric welding is especially adapted to intermittent work and to making welds where it would be very difficult to apply the heat by any other method. When metals are heated by electric current, the central part gets hot first; hence, electric welds are solid throughout. Welds made by the external application of heat are often imperfect in the center, leaving the joint weak.

18. Rail Welding.—A special application of the Thomson welding process is the joining of steel rails, thus making the track one continuous piece. When rails are surrounded by paving, it has been found that they can be joined in this way without being thrown out of line by the expansion and contraction due to heat and cold. Before the weld is made, the surfaces to be welded are thoroughly cleaned either by grinding or by means of a sand blast.

A special form of welder is suspended from a boom carried by a car designed for the purpose; the contacts of the welder are brought against opposite sides of the rail, and, by

means of the current, two pieces of iron are welded on at the joint, one piece on each side. When the pieces have been heated to a welding heat, pressure is applied by means of a hydraulic jack. A joint made in this manner on a 70-pound rail will stand a strain of 279,000 pounds, whereas the maximum strain placed on the rail on account of variations in temperature is 150,000 pounds.

The current for welding is obtained from a transformer, the primary of which is supplied from a rotary converter that takes direct current at 500 volts from the trolley line and converts it to about 300 volts alternating. The average current supplied to the primary of the transformer during a welding operation is about 650 amperes. The electrical conductivity of the joint is as great as that of the rail itself, and under proper conditions four joints per hour can be made.

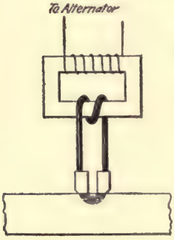


FIG. 5

ANNEALING

19. Electric annealing, another application of electric heating, is a process by which parts of steel plates or castings on which it is desired to perform machine work are softened. The heavy secondary terminals of a special transformer are placed on the part to be softened, as shown in Fig. 5, and a large current sent through it. The part is thereby heated and softened, but other parts of the casting are not affected.

ELECTROLYTIC FORGE

20. An **electrolytic forge,** or **tempering bath,** consists of a metallic-lined vessel containing water or a suitable solution. The solution is made the positive electrode of a direct-current dynamo, while a piece of metal to be heated is made the negative electrode. Fig. 6 illustrates the device; the piece of metal *a* rests on a contact bar *e*, to which the negative side of the circuit is connected, and extends into

the liquid *b*. The vessel *c* has a metal lining *d*, to which the positive side of the circuit is connected.

When the metal is plunged into the liquid and touched to the rod *e*, a current begins to flow through the liquid to the rod and a layer of hydrogen gas immediately forms around the submerged portion. The gas introduces so much resistance between the metal and the liquid that intense heat is

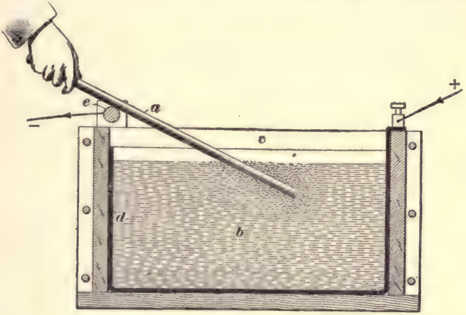


FIG. 6

developed at the surface of the metal. By adjusting the strength of the current and the time it is allowed to flow, any required degree of heat can be obtained, even to melting the metal. This is called the **Hoho process**, after its discoverer, Paul Hoho. In a modification of the process, the metal is brought in contact with only the surface of the liquid, and the liberated hydrogen is burned, thus helping to raise the temperature of the metal.

21. By the Hoho process, metals may be tempered with a great degree of accuracy. The current may be adjusted until the submerged portion of the metal is at the proper temperature and then shut off, leaving the metal in contact with cold water or tempering solution and thus tempering it. Any composition it is desired to use in tempering may be dissolved in the liquid. The heating is under such perfect control that the tempering may be carried to any desired depth from the surface of the metal. Suitable insulating

shields placed over portions of the metal prevent the development of heat on surfaces that are not to be tempered. Large surfaces, such as the wearing surfaces of steel rails, steel axles, shafting, cannon, etc., may be tempered by exposing small portions at a time to the action of the current and the tempering bath, the remaining portions being covered with shields.

By the Hoho process, metals are heated in an envelope of hydrogen gas, which prevents oxidation and thus makes this process very desirable for all operations where oxidation is objectionable. Soldering is one such operation, and metals that are very difficult to solder by any other process can be easily soldered by using an electrolytic forge.

FURNACES

22. When current is made to flow across an air gap between two electrodes, an *electric arc*, a bow-shaped flame of great brilliancy and intense heat, is produced. The temperature of the electric arc is the highest attainable, being in the neighborhood of 3,500° C.; and in an **electric furnace**, in which the arc is confined in an enclosed space, any known

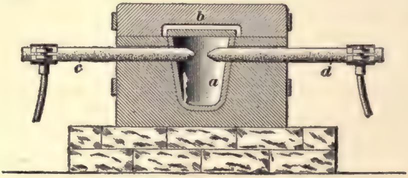


FIG. 7

substance can be melted or vaporized. Carbon is nearly always used for electrodes, as it will best withstand the heat.

Fig. 7 shows a simple form of electric furnace, consisting of a crucible *a* of refractory material surrounded by firebrick and covered by a fireclay slab *b*. Carbon rods *c*, *d* enter from each side and form the electrodes. The arc is started either by sliding one carbon in until it touches the other and then

withdrawing it, or by placing a very small carbon rod, say about $\frac{1}{16}$ inch in diameter, between the carbon points before turning on the current; when the current is turned on, the small rod will very soon burn out and the arc will start.

In some furnaces, the crucible, or containing vessel, is made of carbon and forms one electrode. Many styles of electric furnaces are in use in electrometallurgical and electrosmelting work. They enable the production of high temperatures in very confined spaces and without the admission of air.

AIR AND WATER HEATING

AIR HEATING

23. It requires an expenditure of 18 watts (18 joules per second) to raise the temperature of 1 cubic foot of air 1° F. per second. From this may be calculated the exact power required to raise the temperature of a room a definite amount, provided the room is tightly closed and has non-conducting walls so that no heat can escape. If the room is ventilated, or if the walls conduct heat readily and the rate at which heat escapes cannot be determined, it is impossible to calculate the amount of heat required to raise the temperature to a given point or to maintain it after being raised. Less heat is required to maintain the temperature of a room at a given value than to raise it to that value from a lower one; also, the quantity required for such maintenance is inversely proportional to the amount of ventilation and to the temperature of the outside air.

EXAMPLE.—It is desired to raise the temperature of an electric oven 6 ft. × 10 ft. × 8 ft., inside dimensions, from 60° to 175° F. in $\frac{1}{2}$ hour, the heaters being supplied with current at 500 volts. (*a*) Assuming that no heat is lost, what will be the total current required to heat the oven? (*b*) If two heaters are used in parallel, what will be the resistance of each?

SOLUTION.—(*a*) The cubical contents of the oven is $6 \times 10 \times 8 = 480$ cu. ft. The total rise of temperature is $175 - 60 = 115°$ F., and at 18 joules per cu. ft. for each degree, there would be required for 1 sec.

$18 \times 480 \times 115 = 993{,}600$ joules. Since this energy is to be expended in $\frac{1}{2}$ hr., or 1,800 sec., the joules per sec., or the watts, must be $993{,}600 \div 1{,}800 = 552$; and the current at 500 volts is $552 \div 500 = 1.104$ amperes. Ans.

(*b*) The current taken by each heater is $1.104 \div 2 = .552$ ampere, and the resistance of each heater by Ohm's law, $R = \frac{E}{I}$, is $\frac{500}{.552} = 906$ ohms, nearly. Ans.

In the foregoing example and solution no account is taken of the heat absorbed by the walls of the oven or of that which escapes to the outside air. The quantity of heat actually required would be considerably greater than indicated by the estimates just stated; in practice, it is best, in case the exact quantity has not been experimentally determined, to install with each heater a regulator by means of which the current can be adjusted to suit the requirements.

24. Luminous Radiator.—Every electrical device in which there is any considerable expenditure of energy gives off heat to the surrounding air, even though the device is not intended for this purpose. About 97 per cent. of the energy expended in electric lamps is converted into heat. This fact has been made use of in the manufacture of **luminous radiators,** such as shown in Fig. 8. Three or more large incandescent lamps, especially designed for the production of heat rather than light, are assembled in an ornamental cast-iron casing. Back of the lamps is a polished copper reflector, which throws most of the heat out in front of the heater. These devices are made in two sizes, consuming, respectively, 750 and 1500 watts on either 110- or 220-volt circuits.

FIG. 8

25. Car Heater.—A type of car heater, for use with direct current only, is shown in Fig. 9. The resistance wire

is wound in a long helix with a central flexible insulated cord *a*. The helix is looped over porcelain insulators attached to opposite sides of steel strips *b*, and the whole is protected from

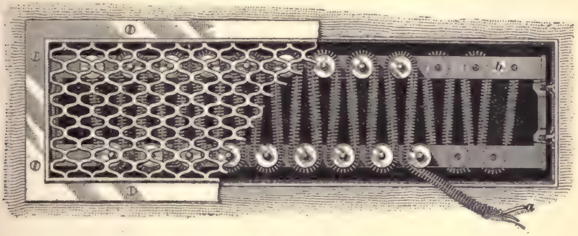


FIG. 9

accidental contact with persons or clothing by suitable gratings. This style of heater is unsuitable for alternating current on account of the high self-induction of such a winding. Many other types of air heaters are in use for electric-car heating.

26. Economy.—At the prices usually charged for energy, the cost of heating by means of electric air heaters is too high to make them economical for continuous use in heating dwelling houses and living rooms; but for removing the dampness from living rooms during the summer and for use for short periods only during the cool days of late spring or early fall, they are practicable.

WATER HEATING

27. It has been found by careful measurement that the conversion of 778 foot-pounds of work into heat will produce exactly the quantity of heat required to raise the temperature of 1 pound of water 1° F.; hence, 778 foot-pounds is called the *mechanical equivalent of heat*. There is .737 foot-pound in 1 joule; hence, the mechanical equivalent of heat expressed in electrical units is $778 \div .737 = 1{,}055$ joules. As 1 gallon of water weighs 8.34 pounds, it requires the conversion of $8.34 \times 1{,}055 = 8{,}798.7$ joules into heat to raise the temperature of 1 gallon of water 1° F. Since 1 joule is equal to

1 watt-second, and there are 3,600 watt-seconds in 1 watt-hour, $8,798.7 \div 3,600 = 2.444$ watt-hours will be required for 1° F. rise in the temperature of 1 gallon of water, provided there are no heat losses.

As a matter of fact, in practical heating operations, considerable heat is always lost; the containing vessel absorbs some heat, while some escapes to the surrounding air. The actual efficiencies of commercial electric water heaters varies between wide limits. Assuming 80 per cent. as a fair average, the energy required to raise the temperature of 1 gallon of water from 50° F. to the boiling point, 212° F., or a total rise of 162° F., is $162 \times 2.444 \times \frac{100}{80} = 495$ watt-hours.

The power required depends inversely on the time in which the work must be done; for example, in the preceding problem, if the gallon of water is to be boiled in $\frac{1}{2}$ hour, $2 \times 495 = 990$ watts will be required, and if in $\frac{1}{4}$ hour, $4 \times 495 = 1,980$ watts will be required.

EXAMPLE.—(*a*) Assuming that an electric water heater has an efficiency of 85 per cent., how much power in watts will be required to raise the temperature of 2 quarts of water from 50° F. to boiling point in 20 minutes? (*b*) What will be the current at 220 volts?

SOLUTION.—(*a*) Since 2 qt. = $\frac{1}{2}$ gal., $\frac{1}{2} \times 2.444$, or 1.222 watt-hours, is required for each degree rise without any losses. For $212 - 50$, or 162° rise, there will be required $162 \times 1.222 = 198$ watt-hours at 100-per-cent. efficiency. At 85-per-cent. efficiency, the energy must be $198 \times \frac{100}{85} = 233$ watt-hours. If the work must be done in 20 min., or $\frac{1}{3}$ hr., the power must be $3 \times 233 = 699$ watts. Ans.

(*b*) The current at 220 volts will be $699 \div 220 = 3.2$ amperes, nearly. Ans.

HEATING APPLIANCES FOR DOMESTIC USE

28. All electric-heating devices for domestic use may be classified as lighting-circuit devices and heating-circuit devices. The **lighting-circuit devices** are those which take about 500 watts or less, and which may be connected to the ordinary branch circuits without any special wiring. The **heating-circuit devices** require special circuits, as the ordinary branch-lighting circuits are not of sufficient capacity.

In view of the fact that the use of domestic electric-heating devices is constantly increasing, new dwelling houses should be provided with special heating circuits having outlets wherever large heating appliances are to be used. Architects and electrical contractors should urge this matter, as the installation of such circuits may save considerable future annoyance and expense.

29. Among the many electrical devices for domestic heating may be mentioned flat irons, coffee pots, teapots, water heaters, chafing dishes, stoves, plate-warming closets, griddles, warming pads, curling-iron heaters, etc. In such devices, the heating circuits are arranged as closely as possible to the surfaces to be heated, so as to make the efficiency of conversion from electricity into useful heat as high as possible. Generally, each manufacturing company has adopted a distinctive method of making and insulating the resistances.

30. Heating Units.—The General Electric Company makes a **cylindrical unit** by winding flat resistance ribbon edgewise in the form of a helix on an arbor, and holding the turns rigidly in place, and at the same time insulating them, with a cement; the whole forms a solid tube, which is wrapped in a thin sheet of mica and enclosed in a shell, or cartridge, as shown in Fig. 10. These units are inserted into close-fitting chambers in flat irons, stoves, or other devices, and are readily replaced if they burn out.

FIG. 10

The same company makes a **flat heating disk** by insulating the surface to be heated with an application of quartz enamel—made by mixing finely divided quartz grains with an insulating enamel—and then winding resistance wire spirally on the enamel. The wire is held in place by applying another coat of enamel over it. The Simplex Electric Heating Company employ the same method, except for differences in the quality of the insulating enamel in which the resistance wire is embedded and sealed.

31. The **Prometheus heating unit,** shown in Fig. 11, consists of a strip of mica carrying a thin layer of non-oxidizable metal firmly secured to the mica by a process of firing. This conducting strip is protected by another piece of mica placed over it, and the whole is bent into any desired form and enclosed in a metallic casing.

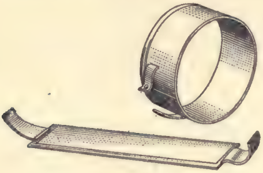


FIG. 11

The resistance used by the Hadaway Electric Heating Company is composed of iron strip, or ribbon, with deep, narrow notches punched in the edges, as shown in Fig. 12. This ribbon is first insulated by a wrapping of mica, and is then laid in molds, where the metal of the heating device is cast around it, thus making the resistance unit an integral part of the heater.

FIG. 12

32. All heating resistances for use with alternating current should be non-inductive, as the production of heat depends only on the square of the current and the ohmic resistance; inductances would cause voltage losses that would result in no additional heat. Non-inductive effects are produced by making the current follow a zigzag

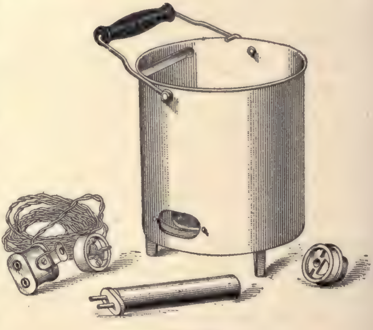
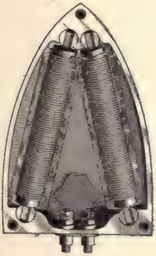


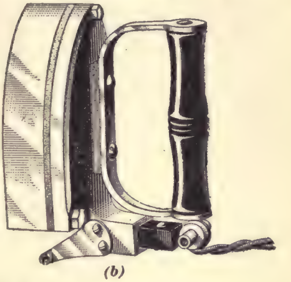
FIG. 13

path, as suggested in Fig. 12; or, if the resistance is in the form of a helix, by making the winding such that the current must travel an equal number of times each way around the helix.

33. Fig. 13 shows the method of applying the General Electric cylindrical units to the bottom of a glue pot. In



(a)



(b)

Fig. 14

some utensils the units are so applied as to be almost entirely surrounded by the liquid to be heated. Fig. 14 (*a*) shows the interior of a Pacific Heating Company flat iron, showing the positions of the two heating units, and (*b*) shows the complete iron with its end so shaped that the iron will stand vertically when not in use. This method of locating the heating units in the iron causes most of the heat to be developed near the point and along the edges of the iron, where it is most needed. The stand, by holding the iron in a vertical position, enables the heat to escape more easily when the iron is not in use, thus avoiding the danger of a burn-out if the current is left on.

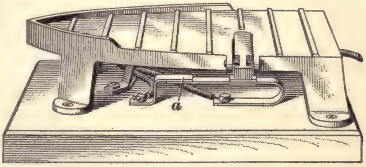


Fig. 15

34. Flat-Iron Stand and Heater. When a flat iron is in use, heat escapes from it much more rapidly than when it is idle; hence, more rapid development of heat is required

in order to keep up a given temperature. If an electric flat iron is allowed to stand idle in a horizontal position with the same current flowing through it as is required while it is in use, the iron will overheat. Fig. 15 shows a **simplex stand** for an electric flat iron; a switch *a* is so arranged that the act of setting the iron on the stand cuts an additional resistance in series with the heating circuit of the iron, so as to prevent overheating and at the same time save current.

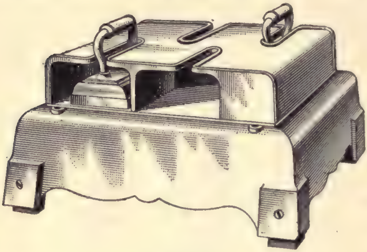


Fig. 16

Fig. 16 shows a **Hadaway heater** for four ordinary irons. Similar heaters are made for any number of irons. An objection to this plan is that the heater remains in operation while the irons are in use, and some heat is thereby uselessly dissipated to the surrounding air.

35. Heating Pad. Fig. 17 shows a **heating pad** to be used as a substitute for a hot-water bottle. This appliance is very useful in hospitals and in private homes. Flexible resistance wire is embedded in non-combustible insulating material, and the same material covers the leads far enough from the pad to avoid all danger of burning the bed clothing.

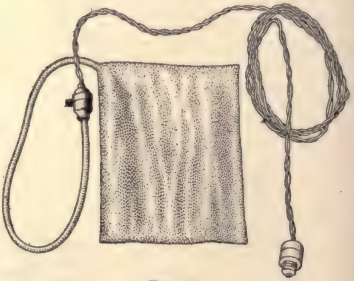


Fig. 17

MISCELLANEOUS HEATING DEVICES

36. Printing and Binding Machinery.—Other appliances that will assist in building up a day load, provided they can be introduced in sufficient number, are heating devices for use in printing and bookbinding establishments; also irons, hot rolls, etc. for laundries, hatters' tools, tailors' irons, glue pots, soldering irons, cigar lighters, etc.

In a printing and bookbinding establishment there are a great many calls for heat, most of them of an intermittent nature. Electric heaters have been found very desirable for such work, on account of the perfect control and ready adaptability of the heat. The Government Printing Office at Washington, D. C., probably has the most extensive equipment of electrical devices for use in printing and bookbinding; these devices range in energy density from .75 to 4 watts per square inch of superficial area of the heaters.

37. Laundry Machinery.—Electric **laundry machinery** has proved to be economical and satisfactory in service, as well as a source of income to the central station. Many laundries are equipped not only with electrically heated flat irons, but also with electrically heated ironing rolls. It is evidently a simple matter to arrange an electric-heating circuit inside an iron cylinder, so that the surface of the cylinder can be kept as hot as desired. Suitably arranged slip rings and brushes conduct the current from the stationary part of the circuit to the revolving part.

38. Power Consumption.—The **power consumption** of electric-heating appliances varies so much with the size of the heater and the rate at which it is designed to furnish heat that it is impossible to give any figures that are generally applicable. The following, however, may be useful: Flat iron, family size (6 pounds), 500 watts; chafing dish, 3-pint size, 500 watts; water heater to raise the temperature of 1 quart from 60° F. to 212° F. (boiling point) in 10 minutes, 650 watts; glue pot, 1-quart size, 440 watts; soldering iron (Vulcan), equivalent of 3-pound soldering copper, 150 watts.

A SERIES OF QUESTIONS AND EXAMPLES

Relating to the Subjects Treated of in This Volume

It will be noticed that the Examination Questions that follow have been divided into sections, which have been given the same numbers as the Instruction Papers to which they refer. No attempt should be made to answer any of the questions or to solve any of the examples until that portion of the text having the same section number as the section in which the questions or examples occur has been carefully studied.

INCANDESCENT AND ARC LIGHTING

EXAMINATION QUESTIONS

(1) (*a*) What causes the filament of an electric incandescent lamp to glow? (*b*) Why must the filament be enclosed in a vacuum?

(2) (*a*) Why is platinum used for leading-in wires? (*b*) What causes lamp bulbs to become blackened, or smoked?

(3) (*a*) Which is the more efficient, a 2.5-watt lamp or a 3.5-watt lamp? Give reason for answer. (*b*) What is meant by mean horizontal candlepower?

(4) Why is it necessary to supply incandescent lamps with the exact voltage for which they were intended?

(5) A room is lighted by sixty 16-candlepower 115-volt incandescent lamps. (*a*) If the average power consumption is 3.24 watts per candlepower, how much current is required? (*b*) How much of this current will flow in each wire of a three-phase circuit that supplies the distribution center from which the lamps are fed?

Ans. $\begin{cases} (a) \text{ 27 amperes} \\ (b) \text{ 15.6 amperes} \end{cases}$

(6) How will an inspection of a direct-current open-arc lamp reveal the direction in which current has been flowing through it?

(7) Mention three advantages of enclosed arcs over open arcs.

(8) What change occurs in an arc lamp, when burning, which enables it to be automatically regulated? Explain briefly.

(9) (*a*) Why is a resistance used in series with a constant-potential direct-current arc lamp? (*b*) What is substituted for this resistance in a constant-potential alternating-current arc lamp?

(10) Explain briefly the arc-regulating mechanism in: (*a*) a differential lamp; (*b*) a shunt lamp.

(11) Why must an arc cut-out switch close the main circuit before it opens a branch circuit of a series system?

(12) (*a*) Make a rough sketch and explain how to locate a break in a series-arc circuit. (*b*) How can a series-arc circuit be tested for a ground?

(13) (*a*) What is meant by a candle-foot? (*b*) If the illumination 1 foot from an incandescent lamp is 50 candle-feet, what will it be at a distance of 6 feet?

Ans. 1.39 candle-feet, nearly

(14) Describe a process of determining the number of 16-candlepower lamps necessary to give a good general illumination in a room 16 feet square and 10 feet high.

(15) For what purposes are reflectors, shades, and globes used?

(16) (*a*) Determine the approximate number of 4-ampere 110-volt alternating-current arc lamps necessary to illuminate properly a storeroom 20 ft. × 60 ft., in which men's clothing is displayed on tables. (*b*) State the reasons that should guide in the choice of glassware (globes or reflecting shades) to be used on the lamps.

ELECTRIC-RAILWAY STATION EQUIPMENT

(PART 1)

EXAMINATION QUESTIONS

(1) How are the single-pole switches for railway-station switchboards made so as to break large currents without destructive sparking? Mention two methods.

(2) What three prime movers are in most general use for street-railway power stations?

(3) (*a*) Name two types of steam boilers. (*b*) Which type of boiler is most used in street-railway power stations? Give reason for answer.

(4) In what form is the energy usually generated for operating electric railways: (*a*) in urban systems? (*b*) in suburban and interurban systems?

(5) (*a*) On air-gap lightning arresters for use on street-railway circuits, why is a resistance inserted in the ground wire? (*b*) What is the principal objection to air-gap arresters?

(6) (*a*) How can a rotary converter be used as a double-current generator? (*b*) Of what does the current in the armature conductors of a double-current generator consist?

(7) Why are high-speed engines more suitable for direct connection to electric generators than those of lower speed?

(8) (*a*) In what units is the output of a railway power station usually expressed? (*b*) What factors are multiplied together by a recording wattmeter?

(9) (*a*) Name the three types of steam turbines extensively used in the United States. (*b*) Which type employs reducing gears?

(10) (*a*) What is boiler scale and (*b*) why is it injurious to boilers?

(11) (*a*) Why is it important that the steam engines in a power station be operated at full load as much of the time as possible? (*b*) Does this consideration also apply with equal force to the generators?

(12) (*a*) What will be the result of setting up a belted generator with too little distance between the driving and the driven pulleys? (*b*) What general rule should be followed in determining the distance to use?

(13) Of what materials are modern switchboards usually made?

(14) Why are switchboards usually arranged in panels?

(15) (*a*) What is a field-discharge switch, and (*b*) why is it used?

(16) (*a*) Name and briefly describe two kinds of exhaust-steam condensers. (*b*) How does a condenser increase the effective pressure on a steam-engine piston?

(17) What is: (*a*) a fuse? (*b*) a circuit-breaker?

(18) (*a*) Why are street-railway generators overcompounded? (*b*) Is it possible to keep the voltage constant on all parts of a railway system? Give reasons for answer.

ELECTRIC-RAILWAY STATION EQUIPMENT

(PART 2)

EXAMINATION QUESTIONS

(1) Make a sketch and describe a method of starting a rotary converter without the necessity of synchronizing devices.

(2) Why is a field break-up switch necessary when starting rotary converters with alternating current?

(3) When are rotary converters preferable to motor generators? Give reasons for answer.

(4) (*a*) If the travel toward a certain section of a railway system becomes so great that the existing installation of feeders to that section will evidently soon be inadequate to carry the current needed, how can a storage battery be used to relieve the situation? (*b*) Would battery regulating devices be necessary? Give reasons for both answers.

(5) Describe a condition that may exist in an electric-railway system, such that a portable substation will be valuable.

(6) What is the object of using time-limit relays in connection with the circuit-breakers in electric-railway power stations?

(7) Make a sketch of connections and explain the carbon regulator used by the Electric Storage Battery Company.

(8) Would you expect a railway generator or converter to spark more, or less, if operating in parallel with storage batteries than if operating alone? Give reasons.

(9) What means are taken to increase the effect of the series-field winding on rotary converters?

(10) Why is it sometimes difficult to start and synchronize a rotary converter by using direct current from another converter already in operation?

(11) Name six disadvantages of storage batteries.

(12) (*a*) What is a reverse-current relay? (*b*) Make sketch and explain one instance of its use.

(13) (*a*) What is meant by peak of load? (*b*) When do the peaks of load usually occur on railway power stations?

(14) How does a storage battery in a railway power station increase the economy of operation?

(15) What means are used to prevent the brushes on rotary converters from wearing furrows in the commutators?

(16) Name and briefly describe two methods used for cooling large transformers.

(17) How can the amount of charge and discharge of a storage battery floating across the line at a distance from the power station be adjusted?

(18) Make a sketch and describe the counter electromotive force system of storage-battery regulation.

INTERIOR WIRING

(PART 1)

EXAMINATION QUESTIONS

(1) In wiring a building for incandescent lamps, why is it important to have the drop in the various circuits limited to a small amount?

(2) (*a*) For what class of work is slow-burning weather-proof wire allowable? (*b*) How must this wire be supported?

(3) Where do the Underwriters' rules require cut-outs to be placed?

(4) How would you calculate the sizes of wire required for house wiring on the three-wire 110–220-volt system?

(5) (*a*) For what are cut-outs used? (*b*) How are they usually constructed?

(6) What are the Underwriters' requirements relating to joints for wires used in connection with interior wiring?

(7) A pair of feeders are to be installed in a factory building to carry current for five hundred 16-candlepower 110-volt lamps from the dynamo room to a center of distribution situated in another building; the total distance (one way) from the dynamo room to the center of distribution is 400 feet and the drop is to be limited to 5 volts: (*a*) What size wire will be required? (*b*) What size wire would be required if the carrying capacity alone were considered? Assume that weather-proof wire is used.

(8) Is the carrying capacity of rubber-covered wire as given by the Underwriters as large as that of weather-proof wire? If not, why?

(9) Are the odd sizes of wire between Nos. 7 and 14 used for interior wiring? If not, why?

(10) In laying out the branch circuits, what determines the number of lamps to be allowed on any one circuit?

(11) Into what three general classes may fires caused by defective wiring be divided?

(12) Fig. I shows a wiring plan of a network that supplies current to 110-volt lamps and motors as indicated: (*a*) Make a sketch and indicate the current flowing at *a*, *b*, *c*, *d*, and *e*. (*b*) Mark the sizes of wire necessary for the various parts of the system in accordance with the

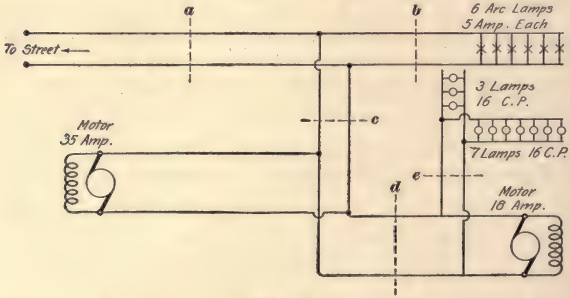


Fig. I

Underwriters' requirements, assuming that rubber-covered wire is used and that current-carrying capacity alone is considered. (*c*) Show where main cut-outs or branch blocks will be required and the size of fuses to be used in order to protect the wire. The individual fuses at the arc lamps and motors need not be indicated.

(13) What are the four most important things to be considered when installing a job of wiring?

(14) When may single-pole switches be used in an interior-wiring installation?

(15) (*a*) What is the smallest size of wire allowable for interior-wiring work outside of fixture wiring? (*b*) If no requirements must be met in regard to line drop, what determines the minimum sizes of wire to be used for a given installation?

(16) Why should the two sides of a circuit always be run in the same conduit when alternating current is used?

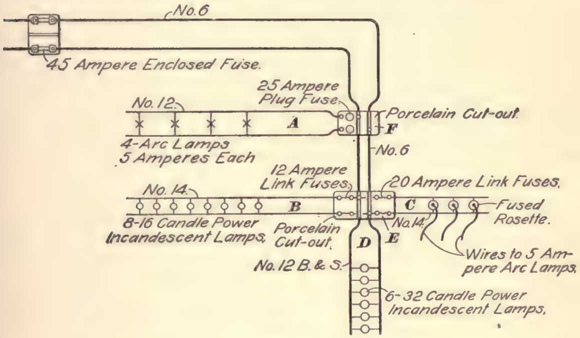


FIG. II

(17) (*a*) Why should unprotected wires never be laid in plaster? (*b*) Why should electric-light wires never be fastened with staples?

(18) In Fig. II, point out the places where the Underwriters' rules are violated and state how you would remedy the defects. All wire is supposed to be rubber-covered.

(19) For what kinds of service are Edison plug fuses suitable?

(20) Under what conditions may a cut-out be omitted when a change is made in the size of wire?

INTERIOR WIRING

(PART 2)

EXAMINATION QUESTIONS

(1) By the aid of Table I, determine the size of wire that would be required for a line (2 wires) extending a distance of 120 feet and carrying 30 amperes with a drop not exceeding 3 volts. Ans. No. 6 B. & S.

(2) After a building has been wired, what tests should be made?

(3) (*a*) What tests and observations does the Underwriters' inspector usually make? (*b*) When should concealed work be inspected by the Underwriters' inspector?

(4) What instrument is generally used in testing out connections, and also in testing for grounds and crosses?

(5) What size B. & S. copper wire should be used, allowing a drop of 2 volts, to supply a group of eighty 110-volt 16-candlepower incandescent lamps at a distance (one way) of 200 feet? Each lamp requires $\frac{1}{2}$ ampere.

Ans. No. 1 B. & S.

(6) What will be the current in the outside wires of an evenly balanced three-wire system supplying sixty lamps, if each lamp requires 52 watts? There is a drop of 2 volts in each outside wire to load center, and the pressure between the outside wires at the center of distribution is 220 volts.

(7) Determine, by means of Table II, what size of wire would be required to transmit 30 amperes a distance of 120 feet (one way) with a line drop not exceeding 3 volts.

Ans. No. 6 B. & S.

(8) Calculate the size of wire necessary to supply fifty 16-candlepower 110-volt lamps located in a group at a distance of 150 feet (one way) from the center of distribution, allowing a drop not to exceed 2 volts. Ans. No. 4 B. & S.

(9) In a building already wired, the drop in a certain feeder, extending a distance of 100 feet (one way), is excessive. The feeder, which consists of a No. 6 wire, carries 40 amperes. What size of wire should be connected in parallel with the No. 6 wire so as to reduce the drop to 2 volts?
Ans. No. 8 B. & S.

(10) What are the Underwriters' requirements: (*a*) about supporting wires in damp places? (*b*) about the use of cut-outs and rosettes in damp places?

(11) (*a*) Where may wooden molding for wires be used? (*b*) Where must it not be used?

(12) What two important conditions necessitate additional precautions for ship wiring?

(13) (*a*) What appliances do the Underwriters require to be placed at a convenient point near where the wires enter a building in addition to the meter that is usually installed? (*b*) In what order should these appliances be placed?

(14) Make a sketch showing how a lamp or group of lamps may be controlled independently from two different points.

(15) Why should good metallic connections be made between all metal conduit pipes, outlet boxes, etc. and the ground?

(16) What kinds of conduits for concealed wiring are now approved by the Underwriters?

(17) What is the so-called loop system of wiring?

(18) What must be done when the size of wire is changed at a junction box?

(19) What precautions must be taken at outlets where the wiring is on the concealed knob-and-tube plan?

(20) How must wires be supported in concealed knob-and-tube work?

(21) Why will two wires safely carry more current than one wire of equivalent cross-section?

(22) A wireman having at hand only some No. 14 wire desires to run a line a distance of 100 feet to supply fifty 16-candlepower lamps requiring $\frac{1}{2}$ ampere each. How many No. 14 wires must be run in multiple in order to have a drop of about 3 volts?

(23) In damp places: (*a*) what kind of sockets must be used? (*b*) how should they be put up?

(24) (*a*) Where may single-pole switches be used? (*b*) Why are they used when possible in preference to double-pole switches?

(25) Why is it that No. 14 wire is generally used for lamp circuits in all ordinary dwelling houses?

INTERIOR WIRING

(PART 3)

EXAMINATION QUESTIONS

(1) Where it is necessary to install wires very cheaply for temporary or occasional use and for some special purpose, such as the illumination of the outside of a building, what are the important items to be kept in view and what are not so important?

(2) What are considered as high-potential circuits?

(3) Why cannot the same protective devices be used on constant-current as on constant-potential circuits?

(4) What sort of switches must be used for constant-current systems?

(5) (*a*) What is a self-restoring annunciator? (*b*) What are its advantages?

(6) To what class of work is the use of high-potential direct current almost exclusively confined in the United States?

(7) Why do the Underwriters' rules prohibit the operation of motors or lights from street-railway circuits, except on street cars, in car barns, or railway power houses?

(8) (*a*) How must a motor and starting resistance box be protected? (*b*) When may single-pole switches be used with motors?

(9) Why is it bad practice to bring the wires of high-voltage systems inside a building?

(10) (*a*) Name two kinds of stage dimmers. (*b*) With what current systems may each be used?

(11) Is it allowable to install electric gas-lighting apparatus on fixtures wired for electric light?

(12) What kind of wire is the best to use for bell and annunciator work when it is run in wet places?

(13) Under what conditions may the circuit-breaker used with a motor take the place of the main switch and cut-out?

(14) What are the ordinary requirements connected with the installation of transformers?

(15) If metal staples are used to fasten down bell and annunciator wires, what precautions should be taken?

(16) When incandescent lamps are connected in series in a circuit, state at least two of the Underwriters' rules concerning such work.

(17) In series gas-lighting systems, why is it necessary to insulate the wires very carefully?

(18) What precautions must be taken when wiring motors?

MERCURY-VAPOR CONVERTERS

EXAMINATION QUESTIONS

(1) (*a*) Name two methods by which an arc may be started in a mercury converter. (*b*) Which method is now generally used?

(2) Give an example of: (*a*) a live load; (*b*) a dead load. (*c*) What is the least current on which a Cooper Hewitt converter will operate?

(3) (*a*) Explain fully why it is necessary to use a choke coil in the circuit leading from the cathode of a mercury converter. (*b*) If the inductance of the choke coil is increased, what is the effect on the direct current from the converter?

(4) (*a*) Mention three uses for which direct current is essential. (*b*) What are some of the advantages possessed by mercury converters over rotary converters and motor-generators?

(5) In starting a General Electric mercury-arc rectifier on a live load, why does the arc sometimes go out when the load switch is closed?

(6) (*a*) At what electrode of a mercury converter is the conducting vapor formed? (*b*) What is the effect of too much vapor in a converter?

(7) (*a*) Does the voltage of a mercury converter change as the current through the converter changes? (*b*) If so, about what is the extent of the change?

(8) (*a*) How is the size of the bulb or tube for a mercury converter determined? (*b*) Why is the ampere capacity of mercury converters usually small?

(9) What are the following: (*a*) electrodes? (*b*) an anode? (*c*) a cathode?

(10) (*a*) How is the voltage of the direct-current circuit from a Cooper Hewitt converter adjusted? (*b*) State the purpose of the dial switch in Fig. 16.

(11) On the Cooper Hewitt converter, what means are adopted to prevent making the wrong connections of the alternating-current leads to the autotransformer?

(12) Make a sketch and describe briefly the winding of an autotransformer.

(13) What system of street lighting now employs mercury-arc rectifiers?

(14) (*a*) What is the chief source of loss in mercury converters? (*b*) What is the approximate efficiency of a 30-ampere converter?

(15) Describe briefly the Cooper Hewitt converter as used for charging storage batteries.

(16) For how high alternating-current voltages can converter tubes be built?

VOLTAGE REGULATION

EXAMINATION QUESTIONS

(1) Why cannot the governor of an engine or a water-wheel be adjusted so that it will maintain constant voltage on the dynamo it is driving when the dynamo load fluctuates?

(2) (*a*) What two things are done to prevent sparking at the relay contacts in a Chapman W. H. C. type voltage regulator? (*b*) How is sparking at the relay contacts prevented in the Belknap type of Chapman regulator?

(3) When a General Electric C R regulator is used on a circuit, how is the flickering of the lamps prevented when the dial switch opens the circuit in passing from one contact to another?

(4) (*a*) What are feeder circuits? (*b*) Of how many wires may a feeder circuit consist?

(5) Explain briefly the chief difference between the principle on which a switch-type, alternating-current feeder regulator works and that on which an induction-type regulator works.

(6) Why is it practically impossible to maintain the same voltage on all parts of a large, direct-current system?

(7) Explain how temperature changes may affect the voltage of a dynamo.

(8) In what way does a Tirrill regulator vary the shunt-field current of the dynamo?

(9) What is the purpose of the short-circuited coil on the armature of a single-phase induction regulator?

(10) Explain why one automatic regulator is sufficient for several compound-wound, direct-current dynamos operating in parallel, while if the dynamos are shunt-wound, a regulator must be used with each.

(11) Why is automatic voltage regulation especially necessary on circuits to which both incandescent lamps and motors are connected?

(12) Why do relay, or voltage-detector, magnets often have a compound winding?

(13) Of what three parts does the dial switch on a General Electric B R regulator consist?

(14) Why are the lamps installed near a large lighting station sometimes made for a higher voltage than those installed at a distance?

(15) What are the essential parts of a Chapman W. H. C. type voltage regulator?

(16) How can single-phase regulators be used on a polyphase circuit?

(17) What is sometimes done to enable the station attendant to know the voltage at a distant center of distribution?

(18) (*a*) What effect will 3-per-cent. increased voltage have on the candlepower of carbon-filament incandescent lamps? (*b*) What will be the effect on the life of these lamps?

MODERN ELECTRIC-LIGHTING DEVICES

EXAMINATION QUESTIONS

(1) (*a*) Why were not the old-style open-arc lamps operated with an arc longer than $\frac{1}{8}$ inch? (*b*) What change has been made that makes it possible to operate arc lamps with arcs 1 inch or more in length?

(2) Describe a system to be followed by an attendant in inspecting and repairing a Nernst lamp.

(3) (*a*) Describe the light obtained from tungsten lamps. (*b*) Why are tungsten lamps likely to come into more general use than any of the other metallic-filament lamps?

(4) (*a*) Of what materials are the electrodes of a magnetite arc lamp made? (*b*) Why is not the positive electrode in this lamp destroyed by the arc?

(5) What is meant by *luminous efficiency* as applied to a source of light?

(6) Describe the connections of two type H mercury-vapor lamps in series. Make a rough sketch.

(7) (*a*) What is the economizer in a flaming-arc lamp? (*b*) Why is it especially necessary to house all the mechanism of a flaming-arc lamp?

(8) (*a*) What is the Moore electric light? (*b*) How can the color of this light be controlled?

(9) How does the preparation of metallized filaments for incandescent lamps differ from that of the ordinary carbon filaments?

(10) Name the essential parts of a Nernst lamp.

(11) (*a*) Of what does the ballast in a Nernst lamp consist? (*b*) For what purpose is the ballast used?

(12) Describe a process of making osmium lamp filaments.

(13) (*a*) What object has been attempted in the Carbone arc lamp? (*b*) How does this lamp compare with other arc lamps in efficiency and in cost of maintenance?

(14) Describe briefly the advantages and disadvantages of mercury-vapor tube lamps, naming three advantages and one very marked quality of the light that renders this lamp useless in some locations.

(15) (*a*) What characteristics have metallized filaments that give them their name? (*b*) What other name would more nearly describe their condition? (*c*) What two chief advantages have metallized-filament lamps over the ordinary carbon-filament lamps?

(16) In flaming-arc lamps, how is the arc made to bow downwards from the tips of the inclined carbons?

(17) Describe briefly the process of making the glowers for Nernst lamps.

(18) To what places is the Moore light applicable?

(19) (*a*) What rare metals are most used for incandescent-lamp filaments? (*b*) Why is it difficult to make metallic-filament lamps for high voltage or small candlepower?

(20) Why can better illumination be obtained from a tube of incandescent gas than from a concentrated source of light?

ELECTRIC SIGNS

EXAMINATION QUESTIONS

(1) Describe an electric carriage call.

(2) How is the quick-break feature obtained in the Solar Electric Company's 10-ampere flasher?

(3) (*a*) What is a monogram letter as used in electric talking signs? (*b*) Describe briefly the connections necessary.

(4) What letters may be made so that they will appear the same when viewed from either side?

(5) (*a*) Describe the making of an Elblight lighting cable. (*b*) How are lamps connected to the cable? (*c*) Where are these cables and lamps most useful?

(6) How may the time be automatically displayed by means of electric lamps so that it can be read from a distance?

(7) When exposed lamp bulbs are used, what may be done to reduce the number of lamps necessary to display the letters properly?

(8) (*a*) What is an automatic time switch? (*b*) Mention an instance where a time switch is useful.

(9) What is a talking sign?

(10) Into what three classes may fixed electric signs be divided?

(11) How do the lamps used in electric signs differ from those used for ordinary illumination?

(12) Of what does the commutator used with a monogram letter consist?

(13) (*a*) What is a thermostat? (*b*) Make a sketch of the connections of a thermostat and describe its operation.

(14) What points should be kept in view in designing an electric sign?

ELECTRIC HEATING

EXAMINATION QUESTIONS

(1) (*a*) Why should fuse wires be 1 inch or more long? (*b*) Why should these wires be enclosed?

(2) (*a*) What is electric annealing? (*b*) How is the process performed?

(3) What should be the condition of the surface of a wire carrying current in order to dissipate heat most rapidly?

(4) (*a*) What special feature, rendering them peculiarly appropriate for their use, have transformers designed and built purposely for thawing frozen water pipes? (*b*) What substitute is used for this special feature when an ordinary lighting transformer is used for the same purpose?

(5) What are some of the advantages to be obtained by the use of electric heat?

(6) (*a*) To what kind of work is electric welding especially adapted? (*b*) What advantage has an electric weld over one made by the ordinary process?

(7) Why should the central-station manager be especially interested in pursuading customers to use electric-heating devices?

(8) (*a*) Describe an electrolytic forge. (*b*) How may an article be tempered in an electrolytic forge?

(9) How should all electric-heating resistances for use with alternating current be made?

(10) In the wiring of dwellings, what provision should be made for electric-heating appliances?

(11) (*a*) Why is alternating current used for such processes as thawing frozen pipes and welding? (*b*) Why is a low-frequency current preferable for welding heavy work?

(12) How much current at 220 volts will be required to raise the temperature of a room 12 ft. × 14 ft. × 10 ft. from 32° F. to 72° F. in 1 hour, making no allowance for losses?

Ans. 1.53 amperes, nearly

A KEY

TO ALL THE QUESTIONS AND EXAMPLES

CONTAINED IN THE

EXAMINATION QUESTIONS INCLUDED IN THIS VOLUME

The Keys that follow have been divided into sections corresponding to the Examination Questions to which they refer, and have been given corresponding section numbers. The answers and solutions have been numbered to correspond with the questions. When the answer to a question involves a repetition of statements given in the Instruction Paper, the reader has been referred to a numbered article, the reading of which will enable him to answer the question himself.

To be of the greatest benefit, the Keys should be used sparingly. They should be used much in the same manner as a pupil would go to a teacher for instruction with regard to answering some example he was unable to solve. If used in this manner, the Keys will be of great help and assistance to the student, and will be a source of encouragement to him in studying the various papers composing the course.

INCANDESCENT AND ARC LIGHTING

(1) (*a*) Electric current passing through the filament heats it to incandescence, thus making it a source of light.

(*b*) In open air, the filament would be almost immediately destroyed by the active element of the air—oxygen. See Art. **2**.

(2) (*a*) See Art. **4**.

(*b*) See Art. **5**.

(3) (*a*) A 2.5-watt lamp, because it requires but 2.5 watts for each mean horizontal candlepower, while a 3.5-watt lamp requires 3.5 watts for the same light. The lamp that gives a candlepower for the least energy is the most efficient. See Art. **11**.

(*b*) See Art. **8**.

(4) Because, if the voltage drops a little, the candlepower decreases very much, while a slight increase of voltage above that for which the lamp was made causes the useful life to be materially shortened. See Art. **11**.

(5) (*a*) By the formula of Art. **12**,

$$I = \frac{60 \times 16 \times 3.24}{115} = 27 \text{ amperes. Ans.}$$

(*b*) In order to balance the system, there must be 9 amperes taken from each of the three phases; and by the formula in Art. **16**,

$$I_m = 9 \times 1.73 = 15.6 \text{ amperes, nearly. Ans.}$$

(6) A crater, or hollow, will be found in the positive carbon tip, and the flow of current is from the positive to the negative carbon. See Art. **19**.

(7) Enclosed arcs consume less carbon; they give a softer light; and, on account of enclosing globes, they make the fire risk lower. See Art. **20**.

(8) The arc gradually lengthens as the carbon tips are burned away; this causes a decrease of current if the voltage at the lamp terminals

is constant, and an increase of arc voltage if the current through the lamp is constant. These changes are made to change the lifting power of magnets, which permits the carbons to fall together when the arc becomes too long. See Art. **21.**

(9) (*a*) To take up surplus voltage, to make the operation of the lamp stable, and to permit the arc voltage to be adjusted. See Arts. **22** and **27.**

(*b*) A reactance, or choke coil. See Art. **53.**

(10) (*a*) See Art. **24.**

(*b*) See Art. **25.**

(11) Because all the lamps on the main circuit are in series with those on the branch circuit, and an opening in the circuit anywhere will put out all its lamps or else cause severe arcing where the opening is made. See Arts. **24** and **30.**

(12) (*a*) Make a sketch similar to Fig. 24 and explain as in Art. **36.**

(*b*) See Art. **37.**

(13) (*a*) See Art. **41.**

(*b*) From the formula of Art. **41,**

$$C = \frac{50}{6 \times 6} = 1.39 \text{ candle-feet, nearly. Ans.}$$

(14) The floor area is $16 \times 16 = 256$ sq. ft. At .25 c. p. per sq. ft., there will be required $256 \times .25 = 64$ c. p. or four 16-c. p. lamps. See Art. **42.**

(15) To soften and diffuse the light, to reflect the light in certain directions, or for purely ornamental purposes. See Art. **43.**

(16) (*a*) There are 1,200 sq. ft. of floor area and there should be expended for illumination about 1.25 watts per sq. ft. (see Table II, department stores, colored material), or a total of about 1,500 watts. Each lamp consumes $4 \times 110 = 440$ watts; three lamps will consume 1,320 watts, or $1,320 \div 1,200 = 1.1$ watts per sq. ft.; four lamps will consume 1,760 watts, or $1,760 \div 1,200 = 1.47$ watts per sq. ft. The material to be illuminated is mostly dark-colored, and four lamps will be more satisfactory.

(*b*) Reflecting shades would be better, because they will throw most of the light downwards where it is wanted; whereas, globes would distribute more light higher in the room where it is not needed.

ELECTRIC-RAILWAY STATION EQUIPMENT

(PART 1)

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(1) See Art. **37.**

(2) Steam engines, steam turbines, and gas engines. See Art. **1.**

(3) See Art. **2.**

(4) See Art. **17.**

(5) (*a*) See Art. **48.**
(*b*) See Art. **49.**

(6) See Art. **29.**

(7) See Art. **9.**

(8) (*a*) See Art. **35.**
(*b*) See Art. **36.**

(9) See Art. **15.**

(10) See Art. **5.**

(11) (*a*) See Art. **10.**
(*b*) See Art. **27.**

(12) See Art. **19.**

(13) See Art. **52.**

(14) See Art. **56.**

(15) See Art. **42.**

(16) See Art. **12.**

(17) See Art. **43.**

(18) See Art. **23.**

ELECTRIC-RAILWAY STATION EQUIPMENT

(PART 2)

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(1) See Fig. 12 and Art. **17**.

(2) Because if the field coils were left connected together while starting, the alternating magnetism set up in the poles by the current in the armature conductors would cause the generation of electromotive forces in the field winding so high as to endanger puncturing the insulation. See Art. **18**.

(3) See Art. **1**.

(4) (*a*) By installing the battery out on the line near the section where the increased demand occurs. This would make the flow of energy through the feeders already installed more nearly uniform, and thus decrease the losses; the battery would also sustain the voltage when cars were operating near it.

(*b*) No; because the line voltage would rise and fall so much, owing to the varying demand for current, that the battery could be left to float across the line. A heavy demand for current near the battery would cause the line voltage to drop enough so that the battery would discharge into the line; but when only a little current was required, the line voltage would rise enough to charge the battery. See Arts. **49** and **50**.

(5) See Art. **35**.

(6) See Art. **3**.

(7) See Fig. 27 and Art. **44**.

(8) Less: because the load on the generator or converter would be more steady. See Art. **46**.

(9) See Art. **13**.

(10) See Art. **15**.

(11) See Art. **37.**

(12) See Fig. 2 and Art. **5.**

(13) See Art. **39.**

(14) By keeping the load on the generating apparatus more nearly constant, thus permitting the use of a smaller generating capacity and the operation of the generators and engines at a more efficient load. See Art. **38.**

(15) See Art. **24.**

(16) See Arts. **8** and **9.**

(17) See Art. **51.**

(18) See Fig. 29 and Art. **45.**

INTERIOR WIRING

(PART 1)

(1) If the drop is excessive, the lamps will not burn with uniform brilliancy, because those near the source of supply get a higher voltage than those far removed, and the lamps on which the voltage is low will give an unsatisfactory light. See Art. **59**.

(2) (*a*) Slow-burning weather-proof wire is allowable for open work in dry places, such as mill wiring, etc. See Art. **38**.

(*b*) It must be supported clear of all woodwork by means of porcelain, glass, or other non-combustible, non-absorptive insulators. See Art. **38**.

(3) A cut-out must be placed as near as possible to the point where service wires enter the building. Cut-outs must be placed wherever there is a change in the size of the wire, unless the fuse in the cut-out protecting the larger wire will protect the smaller wire also. See Art. **28**.

(4) Calculate the wiring as if it were for 220 volts. This will give the size of the outside wires. Make the middle wire of such size that it can carry safely the current required by one side of the system. See Art. **67**.

(5) (*a*) Cut-outs are used to prevent wires being overloaded. They open the circuit whenever the current exceeds the allowable amount and thus prevent the wires from being overheated and burned out.

(*b*) They usually take the form of a piece of soft fusible wire, which melts and opens the circuit whenever the current becomes excessive. In most cases the fuse is enclosed in order to protect it from air-currents and to keep it from coming in contact with other substances. See Art. **27**.

(6) See rule (*c*), Art. **8**.

(7) (*a*) The total current is 250 amperes, allowing $\frac{1}{2}$ ampere per lamp. Resistance $= \frac{E}{I} = \frac{5}{250} = .02$ ohm. Total length of line wire

is $400 \times 2 = 800$ ft., or .8 thousand ft. The resistance per 1,000 ft. must, therefore, be $\frac{.02}{.8} = .025$ ohm. A No. 0000 wire has a resistance of .049 ohm per 1,000 ft., as may be seen by consulting Table IV, so that two No. 0000 wires in multiple will have a resistance of .0245 ohm per 1,000 ft. and will answer in this case. See Art. **63.**

(*b*) If carrying capacity alone were considered, No. 000 weather-proof wire would answer, because the Underwriters allow 262 amperes for this size of wire. See Table I.

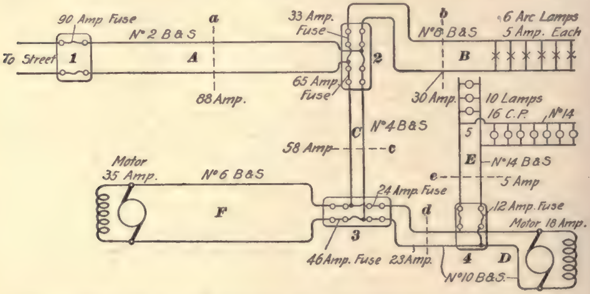
(8) The carrying capacity of rubber-covered wire is lower than that of weather-proof wire, because the rubber covering is subject to gradual deterioration under the action of heat. See Art. **12.**

(9) See Art. **62.**

(10) The amount of energy supplied to any one circuit dependent on one cut-out is limited to 660 watts by rule (*d*), Art. **30**; hence, the number of lamps allowable is easily determined. About ten 16-candle-power lamps per circuit is usually taken as the limit. See Art. **31.**

(11) See Art. **3.**

(12) The illustration given below shows the wiring provided with the necessary cut-outs and with the currents indicated in the various parts.



(*a*) Current at *a*, 88 amperes; *b*, 30 amperes; *c*, 58 amperes; *d*, 23 amperes; *e*, 5 amperes.

(*b*) The sizes of wire will be No. 2 for section *A*, No. 8 for *B*, No. 4 for *C*, No. 10 for *D*, No. 14 for *E*, No. 6 for *F*. See Table I. In each case the wire has been taken that is on the large side, so that the carrying capacity will be ample. If the distances were short, it is probable that so many different sizes would not be used. For example, sections *C* and *F* might both be No. 4, although No. 4 is not absolutely

necessary for section *F*. If, however, the distances were long, it would pay to use the different sizes, as indicated.

(*c*) The actual arrangement of cut-outs may vary somewhat. A cut-out must be placed at each point where there is a change in the size of the wire, and a main cut-out should, therefore, be placed at *1*, and 90-ampere fuses would be the greatest allowable size to use in it. At *2*, we may place a single branch block for *C* and a main block for *B*, or we may use two single branch blocks or one double branch block. In the figure, a double branch block *2* is shown, the side connecting to *B* being fused with fuses not larger than 33 amperes capacity, and the side connecting to *C* with fuses not exceeding 65 amperes capacity. The arc lamps on circuit *B* will each be provided with a cut-out at the point where connection is made to the No. 8 wires. These cut-outs are not indicated in the figure. At *3*, a double branch block may also be used, one side being fused for 24 amperes and the other for 46 amperes, as indicated. To supply branch *E*, a single branch block *4* will be required, and its fuse must not be over 12 amperes capacity. No branch block will be required at *5*, because the size of the wire is not changed there. The current capacity of the fuses indicated in the figure is the same as the current capacity of the wires that they protect. In practice, however, fuses of standard size would be used, and these might not always be of the same capacity as the wire. In any event, the rated capacity of the fuse should not exceed the allowable carrying capacity of the wire it protects.

(13) See Art. **2**.

(14) See rule (*c*), Art. **33**.

(15) (*a*) No. 14 B. & S. See rule (*a*), Art. **8**.

(*b*) The current-carrying capacity as given by the Underwriters.

(16) In order to prevent heating of the conduit and drop in voltage due to inductive effects. See Art. **15**.

(17) (*a*) Because plaster and cement are likely to corrode the insulation and break it down.

(*b*) Staples do not insulate the wire and are likely to cut into the insulating covering with which the wire is provided. See Art. **16**.

(18) On circuit *A*, the current is 20 amperes, which is too much for No. 12 wire; No. 10 should be used. Each arc lamp should also be provided with a cut-out where the wires running to the lamp tap on to the mains. Circuit *B* is all right except that it is connected to link fuses mounted on a porcelain double branch block. Circuit *C* is also supplied through link fuses. A double branch block carrying enclosed fuses should be substituted. Circuit *C* is overloaded; the wire should be at least No. 12 and it would be better if made No. 10 in order to allow for the larger current taken by the lamps at starting.

Also fused rosettes are not allowable for the individual cut-outs used with the lamps. Each lamp takes 5 amperes and fused rosettes are not allowed to carry more than 3 amperes. An enclosed fuse cut-out should be substituted in each case. Circuit *D* is of No. 12 wire and provides ample carrying capacity for the lamps connected to it. However, it has no protection other than the 45-ampere main fuses and it would be necessary to insert a fuse block at *E* where the No. 12 wire is attached to the No. 6, this block being fused for not more than 17 amperes.

(19) For use on 125-volt lines or on three-wire systems with grounded neutral where the pressure between the outside lines does not exceed 250 volts. See Art. **52**.

(20) When the fuse in the larger wire is of such size that it will melt before the carrying capacity of the smaller wire is exceeded. See Arts. **28** and **29**.

INTERIOR WIRING

(PART 2)

(1) A line 120 ft. long having a drop of 3 volts would be the same size as a line $\frac{120}{3} = 40$ ft. long having a drop of 1 volt. In Table I, under 40 and on the same horizontal line with 30, we find No. 6 as the size wire required.

(2) Tests should be made to see that all connections are correct, and also to detect any grounds or crosses between wires. All circuits should be tested before fixtures of any kind are put up, and each fixture should be tested after it is wired, but before it is put in place. See Art. **52**.

(3) (*a*) See Art. **54**.
(*b*) Before the building is lathed and plastered.

(4) See Art. **52**.

(5) The total current $= 80 \times \frac{1}{2} = 40$ amperes. By formula **1**, the resistance per 1,000 ft. r_m of the proper size wire to use equals $\frac{1{,}000 \times 2}{2 \times 200 \times 40} = .125$ ohm per 1,000 ft. This would require a No. 1 wire, which has a resistance of .124 ohm per 1,000 ft.

(6) The voltage across the outside wires at the lamps $= 220 - 4 = 216$ volts. Substituting in formula **7**, we have current $= \frac{60 \times 52}{216} = 14.4$ amperes. Ans.

(7) As in Art. **9**, divide the current by the drop, which gives $\frac{30}{3} = 10$. Now follow down in the column under 10 amperes until the nearest distance to 120 ft. is obtained. This will be found to be 121, and to the left of this in the first column will be found the size of wire required, namely, No. 6 B. & S.

(8) The fifty lamps will require 25 amperes. Substituting the values given in formula **5**, we have circular mils $= \frac{21.6 \times 150 \times 25}{2} = 40{,}500$, or between a No. 4 and No. 5 B. & S. No. 4 wire would be used.

(9) No. 6 wire has a cross-section of 26,250 circular mils, approximately. The drop is to be 2 volts, the current 40 amperes, and the distance 100 ft.; hence, from formula **5**, the required cross-section of wire in circular mils $= \frac{21.6 \times 100 \times 40}{2} = 43{,}200$. The cross-section of the wire to be connected in parallel with the No. 6 wire already installed will be $43{,}200 - 26{,}250 = 16{,}950$. No. 8 B. & S. has about 16,510 circular mils and would be the nearest size. See Art. **14**.

(10) (*a*) and (*b*) See Art. **15**.

(11) (*a*) Wooden molding may be used in finished houses on ceilings and walls, and in show windows for temporary purposes, where it is desirable to hide the wire and give the work a neat appearance.

(*b*) It must not be used in concealed work, in damp places, or in any place where the difference of potential is over 300 volts. See Art. **50**.

(12) See Art. **57**.

(13) (*a*) A main switch and cut-out.

(*b*) The cut-out should be placed nearest the point where the wires enter, then the switch, and finally the meter. See Art. **26**.

(14) By means of two three-point switches, one at each point from which it is desired to control the lamps. Make a sketch similar to (*a*) or (*b*), Fig. 18. See Art. **29**.

(15) So that if a wire comes in contact with any section of a conduit or fitting, there will be afforded a direct path to ground through which current may escape to earth. This prevents the current leaking to ground through any other paths and thereby reduces the likelihood of a fire. See Art. **47**.

(16) See Art. **40**.

(17) The loop system is one in which the same pair of wires passes in series through all outlets at which lamps to be connected on that circuit are located; that is, no branch circuits are tapped on except at outlet or junction boxes. See Art. **42**.

(18) See Art. **43**.

(19) The wires must be brought out, for combination fixtures, through flexible insulated tubes in such a manner that they cannot touch gas pipes, metal work, or plaster. The insulating tubes must

extend as far back as the last insulating support. If there is a gas pipe at the outlet, the tubes must extend at least as far as the end of the gas cap. See Art. **18** and rule (*d*), Art. **19.**

(20) They must be rigidly supported on non-combustible, non-absorptive insulators that keep the wires at least 1 inch from the surface wired over, and should be kept at least 5 inches apart and run on separate timbers or studding whenever possible. Sometimes, especially where a large number of wires come together near the junction or panel boards, it is impossible to keep the wires 5 inches apart, and in such cases they can be run in an armored cable or conduit. See Art. **19.**

(21) Since the two wires have a greater surface area than the one wire of equivalent cross-section, they can radiate the heat faster and hence can safely carry more current. See Art. **13.**

(22) The current will be 25 amperes; hence, from formula **5,** circular mils $= \frac{21.6 \times 100 \times 25}{3} = 18{,}000$. No. 14 B. & S. has a cross-section of 4,107 circular mils and $\frac{18{,}000}{4{,}107} = 4.4$, nearly. Four No. 14 wires on each side of the circuit will give somewhat under the required cross-section, and hence the drop will be slightly over 3 volts. Five wires on each side will give more than the required cross-section. If desired, four wires can be used on one side and five on the other, thus giving the allowable drop almost exactly, but four wires will likely be near enough. See Art. **14.**

(23) (*a*) Waterproof sockets.

(*b*) They should be connected and hung by separate rubber-covered stranded conductors, not smaller than No. 14 B. & S. The two conductors should preferably be twisted together when their length is over 3 ft. They should be soldered directly to the circuit wires, but supported so that the weight of the lamp socket and wires will not be borne by the circuit wires. Rosettes should not be used. See Art. **15.**

(24) (*a*) A single-pole switch may be used where it does not control over 660 watts.

(*b*) Because they cost less and the wiring is simpler and cheaper. See Art. **28.**

(25) Because not more than 660 watts are allowed on one circuit by the Underwriters and No. 14 is plenty large enough to carry the current safely; moreover, the distances are usually so small that the drop is never too large on 110-volts or higher pressure systems, even with the maximum allowable number of lamps on the branch circuits. No. 14 wire being the smallest size allowed by the Underwriters is therefore used for most branch circuits. See Art. **24.**

INTERIOR WIRING

(PART 3)

(1) It is important to burn the lamps at a proper and uniform voltage, the drop or efficiency being a secondary matter; hence, a large drop may be allowed and comparatively small wires may be used, but lamps of the proper voltage should be used even if this requires lamps of different voltages in the various parts of the circuit or system. See Art. **10.**

(2) See Art. **16.**

(3) Because a protective device for use on a constant-potential circuit is made to open the circuit in order to protect it, but on a constant-current system, it must *short-circuit* and *not open* the circuit. See Art. **23.**

(4) See Art. **23.**

(5) (*a*) A self-restoring annunciator is so constructed that when a button is pushed, its corresponding drop falls. The next call operates a magnet that moves a restoring device, thus resetting the first drop.
(*b*) See Art. **41.**

(6) See Art. **17.**

(7) Since one side of the system is grounded, it is very easy for the current to leak to earth, and hence the fire risk is great, to say nothing of the risk from shocks. See Art. **29.**

(8) (*a*) A motor and starting resistance box must be protected by a cut-out and controlled by a switch that shows plainly whether it is on or off.
(*b*) Single-pole switches may be used with motors of $\frac{1}{4}$ horsepower or less and then only on low-tension circuits. See Art. **28.**

(9) It is dangerous to life and, moreover, a lightning discharge can easily start an arc, and an arc once started will persist even though the points between which it plays are separated several inches; hence, it is liable to cause a fire. See Art. **17.**

(10) (*a*) Resistance boxes and reactive, or choke, coils.

(*b*) Resistence boxes may be used on direct- or alternating-current systems, but reactive, or choke, coils, although the more economical of the two, can only be used on alternating-current systems. See Art. **9.**

(11) See Art. **67.**

(12) It is best to use rubber-covered wire in very moist or wet places for bell and annunciator wiring. See **42.**

(13) When the circuit-breaker opens all the wires leading from the line to the motor. See Art. **28.**

(14) Without special permission transformers must not be placed inside a building, except in central stations, and if a transformer is fastened to an outside wall, it must be separated from the wall by substantial supports. When transformers are placed in buildings, they must be located in a special fireproof enclosure located near the point where the wires enter the building. See Art. **19.**

(15) See Art. **42.**

(16) See Art. **26.**

(17) Because all the air gaps at the burners in one circuit are in series, and hence offer a great resistance to the sparking current; and since a current will take the easiest path to ground, it follows that the current will jump to ground instead of across all the spark gaps if there is a point where the resistance to ground is less than the resistance of the gaps. Consequently, high insulation is essential. See Art. **68.**

(18) State the main requirements as given in Arts. **27** and **28.**

MERCURY-VAPOR CONVERTERS

(1) (*a*) By applying a very high voltage, possibly 25,000 volts, between the electrodes, or by tilting the bulb until the mercury forms a continuous stream between the electrodes, and then righting the bulb to break the stream. See Arts. **10** and **17**.

(*b*) The second method. See Art. **17**.

(2) (*a*) See Art. **18**.
(*b*) See Art. **25**.
(*c*) See Art. **24**.

(3) See Art. **16**.

(4) See Art. **9**.

(5) See Art. **32**.

(6) (*a*) See Art. **10**.
(*b*) See Art. **11**.

(7) See Art. **39**.

(8) (*a*) The quantity of current it must carry determines the size of a converter bulb. It must be large enough to afford sufficient condensing surface for the mercury vapor. See Art. **19**.

(*b*) See Art. **37**.

(9) See Art. **4**.

(10) (*a*) By inserting the plugs on the ends of the wires leading to the converter in different holes in the autotransformer plugboard, and by varying the position of the core of the regulating coil. See Arts. **18** and **23**.

(*b*) To adjust the voltage of the direct-current circuit that is connected to the rectifier. See Arts. **32** and **34**.

(11) The plugs on the ends of the wires leading from the autotransformer to the converter terminals are made of such size that they cannot be inserted into any holes in the plugboard where they are not intended to go. See Art. **22**.

(12) See Fig. 1 and Art. **7.**

(13) See Art. **41.**

(14) See Art. **38.**

(15) See Art. **19.**

(16) See Art. **40.**

VOLTAGE REGULATION

(1) The inertia of the moving parts of the engine and dynamo is too great to permit speed changes quick enough to compensate for a fluctuating dynamo load. See Art. **9**.

(2) (*a*) The relay magnet has a short-circuited winding that prevents sudden changes of flux, and incandescent lamps connected across the relay contacts absorb what little inductive kick many remain. See Art. **15**.

(*b*) The magnetizing effects of the windings on the working solenoid neutralize one another, so that when the circuit opens there is no sudden dying out of magnetism. See Art. **17**.

(3) The movements of the switch blade are effected through a compression spring, and the blade is retarded by a catch until the spring is compressed. When the blade slips loose from the catch, it snaps over to the next contact so quickly that the lamps on the circuit do not flicker. See Art. **27**.

(4) See Art. **3**.

(5) See Art. **25**.

(6) All the feeders may not be carrying the same proportion of their full load, which makes the drop in some feeders greater than in others, and as the voltages at distant points equal the station voltage less the amount of the drop in the feeders and the lines to those points, the voltages at the centers of distribution may be dissimilar. See Arts. **6** and **7**.

(7) See Art. **2**.

(8) By short-circuiting the field rheostat, thus allowing a large field current to flow whenever the voltage of the dynamo drops below a fixed minimum limit. As soon as the voltage of the dynamo rises to a fixed maximum limit, the short circuit is opened automatically, leaving the rheostat again in circuit, thus causing the field current to drop to its original value. See Art. **18**.

(9) It prevents the building up of a large flux by the secondary coil while the primary coil is in an inactive position, and thus prevents the introduction of a large inductance into the feeder circuit. See Arts. **33** and **34**.

(10) See Art. **20**.

(11) Because motors usually require a varying current, especially if they are stopped and started often. The varying currents cause a varying drop in circuits, thus varying the voltage at the lamp terminals. See Art. **4**.

(12) A compound winding is used in order to keep the pressure constant at a point distant from the power station. The shunt winding magnetizes the magnet core in proportion to the pressure at the station, and the series winding weakens this magnetism in proportion to the drop in the feeders to the distant point. See Art. **12**.

(13) See Art. **28**.

(14) See Art. **7**.

(15) See Art. **11**.

(16) By connecting the regulators to two-wire feeder circuits supplied by the different phases of the polyphase circuit. See Art. **41**.

(17) See Art. **8**.

(18) (*a*) According to the curves in Fig. 1, a rise of 3 per cent. in the voltage; that is, to 103 per cent. of normal volts, causes the lamps to give 118 per cent. of normal candlepower, an increase of 18 per cent. Ans.

(*b*) The point on the life curve, Fig. 1, directly opposite 103 per cent. of normal volts, is directly over 52 per cent.; that is, the life of the lamps would be decreased $100 - 52 = 48$ per cent. Ans.

MODERN ELECTRIC-LIGHTING DEVICES

(1) See Art. **61**.

(2) See Art. **38**.

(3) See Art. **23**.

(4) See Art. **75**.

(5) See Art. **1**.

(6) See Fig. 21 and Art. **45**.

(7) (*a*) See Art. **65**.
(*b*) See Art. **68**.

(8) (*a*) See Art. **53**.
(*b*) By the selection of the gas to be mingled with the rarefied air in the tube. See Art. **54**.

(9) The same process is used for both, except that the metallized filaments are subjected to the additional operation of being heated to a temperature of from 3,000° to 3,700° C., both before and after the flashing process, in an electric-resistance furnace having the form of a carbon tube. See Art. **3**.

(10) See Art. **26**.

(11) See Art. **31**.

(12) See Art. **17**.

(13) See Art. **74**.

(14) See Art. **50**.

(15) (*a*) The metallized filaments have positive temperature coefficients and a lower resistance than the carbon filaments; that is, their characteristics resemble those of a metal. See Art. **4**.
(*b*) Graphitized. See Art. **4**.
(*c*) Increased economy and better light. See Art. **5**.

(16) See Art. **63.**

(17) See Art. **27.**

(18) See Art. **57.**

(19) (*a*) See Art. **9.**

(*b*) Because of the great length of filament required, and the difficulty of supporting it. See Arts. **11** and **21.**

(20) Because with the tube the source of light is distributed and the quantity of light falling on an object is greater than that given by the law of inverse squares, which holds true for a concentrated source of light. Moreover, with the tube, sharply defined lights and shadows are avoided. See Art. **39.**

ELECTRIC SIGNS

(1) See Art. **30.**

(2) The contacts are held together by the combined pull of a coiled spring and a permanent horseshoe magnet. The expansion wire cools, contracts, and finally overcomes the holding power of the magnet and spring, and the contacts fly apart quickly. See Art. **16.**

(3) (*a*) A monogram letter is a group of lamps so arranged that a large number of different letters, figures, or characters may be displayed by lighting different lamps of the group. See Art. **23.** (*b*) See Art. **24.**

(4) See Art. **8.**

(5) See Art. **22.**

(6) By a group of lamps with a suitable commutating device arranged to operate in synchronism with the movements of a clock. The commutator changes the connections to the lamps at regular intervals, usually once every minute, so that the lamps display the figures showing the time. See Art. **29.**

(7) See Art. **7.**

(8) See Art. **20.**

(9) See Art. **28.**

(10) See Art. **2.**

(11) See Art. **10.**

(12) See Art. **25.**

(13) (*a*) See Art. **11.**
(*b*) See Fig. 10 (*b*) and Art. **12.**

(14) The aim should be to design a sign that can be read by the greatest possible number of people for the longest possible time and that will convey the strongest possible impression. See Art. **2.**

ELECTRIC HEATING

(1) See Art. **3.**

(2) See Art. **19.**

(3) The surface should be rough and blackened. See Art. **2.**

(4) (*a*) They have large magnetic leakage, which causes high inductive drop when the secondary current becomes excessive, and thus prevents injury in case of accidental short circuit.

(*b*) A choke coil. See Art. **10.**

(5) See Art. **5.**

(6) See Art. **17.**

(7) See Art. **6.**

(8). (*a*) See Art. **20.**
(*b*) See Art. **21.**

(9) See Art. **32.**

(10) See Art. **28.**

(11) See Arts. **8, 12,** and **13.**

(12) The total volume of air to be heated is $12 \times 14 \times 10 = 1{,}680$ cu. ft., and the number of degrees through which the temperature is to be raised is $72 - 32 = 40°$ F. At 18 joules, or watt-seconds, per cu. ft. for each degree rise there will be required $1{,}680 \times 18 \times 40 = 1{,}209{,}600$ watt-seconds. As there are 3,600 watt-seconds in 1 watt-hour the requirements in watt-hours will be $1{,}209{,}600 \div 3{,}600 = 336$, and as the time is 1 hr., the power in watts that is required is $336 \div 1 = 336$. At 220 volts the current must be $336 \div 220 = 1.53$ amperes, nearly. Ans. See Art. **23.**

INDEX

NOTE.—All items in this index refer first to the section (see the Preface), and then to the page of the section. Thus, "Air heating, §57, p21," means that air heating will be found on page 21 of section 57.

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